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THE IAR HIGH REYNOLDS NUMBER TWO-DIMENSIONAL TEST FACILITY – A DESCRIPTION OF EQUIPMENT AND PROCEDURES COMMON TO MOST 2-D AIRFOIL TESTS

by

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Institute for Aerospace Research

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THE IAR HIGH REYNOLDS NUMBER TWO-DIMENSIONAL TEST FACILITY - A DESCRIPTION OF EQUIPMENT AND PROCEDURES COMMON TO MOST 2-D AIRFOIL TESTS

INSTALLATION D'ESSAIS BIDIMENSIONNELLE POUR NOMBRE DE REYNOLDS ÉLEVÉ DE L'IRA - DESCRIPTION DU MATÉRIEL ET DES MÉTHODES COMMUNES À LA PLUPART DES ESSAIS SUR LES PROFILS BIDIMENSIONNELS

by/par

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SUMMARY

This report describes features and operational procedures which are common to the great majority of wind tunnel test projects conducted in the Two-Dimensional (2-D) Test Facility of the Institute for Aerospace Research 1.5m Trisonic Blowdown Wind Tunnel in Ottawa, Canada. It is intended to be used as a reference document describing the 'facility specific' aspects of tests performed in the above facility, to be referred to by test reports for individual projects, so allowing those reports to concentrate on aspects which are specific to the particular model and test. The report describes the 2-D test facility as modernized by the commissioning of a new interchangeable 2-D test section module in early 1989. The document will be updated periodically to ensure that it correctly reflects current capability and practice.

RÉSUMÉ

Le présent rapport décrit les caractéristiques et les méthodes d'utilisation qui sont communes à la grande majorité des projets d'essais en soufflerie réalisés dans l'installation d'essais bidimensionnelle de la soufflerie trisonique à rafales de 1,5 m de l'Institut de recherche aérospatiale, à Ottawa (Canada). Il est destiné à servir de document de référence donnant une description des aspects "propres à l'installation" des essais effectués dans l'installation susmentionnée, auquel on pourra se reporter dans les rapports d'essais des projets individuels, de sorte que dans ces derniers rapports on puisse mettre l'accent sur les aspects propres au modèle et à l'essai particuliers. Dans le rapport, on décrit l'installation d'essais bidimensionnelle comme une installation qu'on a modernisé par la mise en service au début de 1989 d'un nouveau module à veine d'essai bidimensionnelle interchangeable. On mettra le document à jour périodiquement afin de s'assurer qu'il reflète bien la capacité existante de l'installation et les méthodes qui y sont applicables.

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ALBAR, $\overline{\alpha}$	angle between model chord line and balance X-axis
ALPHA, α	average incidence of north and south balances
α_c	model angle of attack, corrected for $\overline{\alpha}$ and $\Delta\alpha_{flow}$ **but not for wall interference**
$\Delta\alpha$	correction to angle of attack due to wall interference
ALPHAC, ALPHACL	corrected model angle of attack
ALPHAN, ALPHAS, α_n, α_s	incidence of north and south balances
$\Delta\alpha_{flow}$	flow angularity in W/T vertical plane
b	tunnel width (15" or 0.381m)
c	model chord
C_D, C_D'	drag coefficient
CDB	drag coefficient from sidewall balance
CDP	drag coefficient from integration of pressure distribution
CDW	average of 'C_D' from specified wake probes
CDW1, CDW2, etc	'C_D' values from individual wake probes
C_L	lift coefficient
CLB	lift coefficient from sidewall balance
CLP	lift coefficient from integrated pressure distribution
CmB	sidewall balance pitching moment coefficient about the reference point
CM-C/4	pitching moment coefficient about model quarter chord
CmLE	pitching moment coefficient about the airfoil leading edge, from pressure integration
CmRP	pitching moment coefficient about the reference point from pressure integration
CN	normal force coefficient
CNB	normal force coefficient from sidewall balance
CNP	normal force coefficient from integration of pressure distribution
CP, Cp	pressure coefficient = (P - Pinf)/Qinf
CP(C-F)	'ceiling - floor' pressure difference coefficient
Cpcrit	critical pressure coefficient
Cpstag	stagnation pressure coefficient
CX	axial force coefficient
CXB	axial force coefficient from sidewall balance
CXP	axial force coefficient from integration of pressure distribution
DCDW1, DCDW2, etc.	deviation of individual wake probe C_D values from average of specified probes
DCP45R	difference between the 'reference' and centreline static pressures as a coefficient
M, Minf	free stream Mach number
MCOR	Mach number corrected for wall interference effect
MCORR, ΔM	correction to Mach number due to wall interference
Mnom	Mach number based on 'reference' static pressure
N1, N2, XN	north side) sidewall balance measured
S1, S2, XS	south side) component loads
NF, NA, XT	sidewall balance **total** load components
μ	viscosity of air at free stream conditions
P	local static pressure

PA, Patm	atmospheric pressure
Pcorr	correction to 'reference' static pressure to give centreline static pressure
Pinf	free stream static pressure
PI, P45R, Ps	measured 'reference' static pressure
P0, Po, PT1	stagnation pressure
Psb	sidewall 'suction box' pressure
Q, Qinf	corrected free stream dynamic pressure
Qnom	dynamic pressure based on 'reference' static pressure measurement
REC, Rc	Reynolds number based on model chord length
RFT, Re/ft	Reynolds number per foot
S	force and moment coefficient reference area (= tunnel width x model chord)
Tinf	static temperature
T0, To	stagnation temperature
Uinf, Vinf	free stream velocity
V/U, Vn/Vinf	sidewall suction 'velocity ratio'
Vn	velocity normal to the porous sidewall

1 INTRODUCTION

Following completion of each test performed in the IAR 2-D High Reynolds Number Test Facility it is normal practice to issue a test report, which heretofore has contained general information on features of the test facility as well as information specific to the particular test. The great majority of test programs conducted in the 2-D test facility consist of quite standard measurements performed with instrumentation which is an integral part of the test facility and common to all tests. For this reason significant portions of test reports for different projects often are quite similar to each other when reporting this 'facility dependent' information. This report, containing descriptions of these common aspects of 2-D tests, has been prepared to avoid further duplication of effort.

The report describes the 2-D test facility, the data acquisition system, and the instrumentation and procedures used in performing those measurements which generally are regarded as 'standard' for almost all tests. These include, for example, measurements of the forces and moments by two 3-component sidewall balances, of the model surface and wind tunnel wall static pressure distributions using a pressure scanning system, of the model's drag as determined from the total pressure deficit in the wake, and of the level of suction used to control the sidewall boundary layers. Where appropriate, operational procedures are described, as for example in specification of the suction settings recommended for sidewall boundary layer control, and in the use of programmed 'wake functions' which can help to track the model wake position as it changes with incidence. The data acquisition and reduction procedures are also described, and samples are given of the reduced data output in both tabular and graphic form.

Throughout the report all units and dimensions are specified using the **Imperial** system of units as the original facility was designed and built using this system. In most instances **Metric** conversions are supplied in parentheses but it should be noted that these conversions are "soft", i.e. rounded to some accuracy which is reasonable in the context of the measurement. Exceptions to this policy will be found in the figures, where only Imperial units are used to define the dimensions and/or performance of the facility and its equipment, and in Appendix A. In this latter case the units are again Imperial as it is in these units that all computations are performed; conversions to Metric or other units are made at the customer's request, but are applied only to the final reduced data.

2 TEST FACILITY

The IAR High Reynolds Number 15" x 60" (0.38m x 1.5m) Two-Dimensional Test Facility is operated by the High Speed Aerodynamics Laboratory (HSAL) of the Institute for Aerospace Research (IAR), (formerly the National Aeronautical Establishment), and is located in Ottawa, Canada. Between its commissioning in September 1969 and March of 1988 this 2-D test facility had been comprised of a solid-walled channel insert which was mounted inside the 3-D perforated wall transonic test section of the IAR 1.5m Trisonic Blowdown Wind Tunnel, and utilised the existing perforated ceiling and floor. In the Spring of 1989 a new 2-D interchangeable test section module was commissioned. It was introduced to modernize the facility in respect of current test section design practice, and to provide for more efficient changes between the various test section configurations required for 2-D and 3-D, (both full-model and half-model), testing. With the 'interchangeable module' concept, (Figure 1), completely separate 2-D and 3-D test sections are used, the required section being inserted into the plenum chamber shell using a special transporter cart. When not in use the test section modules, (presently 2-D and 3-D only, but with provision for a third at a later date), are stored in an annex adjacent to the wind tunnel room, in which location they are accessible for some model rigging tasks during normal wind tunnel operations. The major components of the 2-D test facility are identified in the cutaway view given in the upper part of Figure 2, and the interchangeable 2-D test section module is illustrated in the lower part of the figure. The 4:1 inlet contraction section extends forward of the interface between the 2-D module and the main wind tunnel nozzle section, (see top of Figure 3(a)), and is secured to the main nozzle section when installed. Figure 3(a) shows views of the 2-D module in process of installation, while Figure 3(b) shows the module fully installed in the plenum chamber of the wind tunnel.

Significant features of the 2-D facility are outlined below and in the section describing the test instrumentation, and further information is contained in References 1 to 5; of these the first three references actually refer to the old test section configuration, but much of the information is still applicable as many of the basic systems are essentially unchanged.

2.1 Test Section

The test section has a width of 15 inches (0.38m) and a height of 60 inches (1.5m) with solid sidewalls and porous ceiling and floor. The new test section utilises the same sidewalls and much of the same equipment as did the original test section, (sidewall balances, wake rake, sidewall boundary layer control system), but the ceiling and floor are new and now form an integral part of the test section module. These are perforated with holes inclined toward the oncoming flow at 60 degrees to the vertical compared to the normal holes of the old test section; the inclined holes are also equipped with integral splitter plates for edgetone noise suppression. The porosity of the top and bottom walls is adjustable between approximately 0.5% and 6% using sliding backup plates made of brass which replicate the pattern of slanted holes, but without the splitter plates. The much lower percentage porosity required with the new wall configuration compared to the old, (20.5% using holes normal to the wall), results from the reduced resistance to outflow that is provided by the inclined holes. Initial calibrations have indicated that fairly low porosity settings give the best empty tunnel characteristics, and it is presently recommended that a porosity setting of 2% be used for both ceiling and floor. Results from the initial calibrations are given in References 4 and 5.

2.2 Sidewall Boundary Layer Control

The relatively thick boundary layer which develops on the sidewalls of the wind tunnel nozzle section upstream of the 2-D section is diverted by bleed slots located at the entry to the two-dimensional 4:1 contraction as indicated in Figure 2. The new boundary layer developing on the inlet contraction and the 2-D section sidewalls then is thinned or removed by suction through porous inserts in the walls at the model station, in order to minimize interaction effects between the model and wall boundary layers, (and shock waves when present), and maintain a good two-dimensional flow. The sidewall suction areas are faced with a commercially available material called Rigimesh, which is composed of compacted layers of stainless steel gauze which have been sintered together. This material is relatively resistive to flow, and has a fairly fine mesh on one face so that the surface exposed to the airflow is reasonably smooth. In each of the sidewalls the Rigimesh plate is backed by an enclosed 'suction box' which is vented to the atmospheric environment of the wind tunnel room through an 8" (20 cm) diameter pipe, a slide valve which provides control of the suction mass flow, and a diffuser section; this arrangement is illustrated in Figure 4. Initially the system was designed to operate only in a 'dump to atmosphere' mode, but to extend its operation to higher Mach numbers where the difference between local test section static pressure and atmospheric pressure becomes inadequate, the diffuser sections were later equipped with ejectors. The amount of suction required to achieve good two-dimensional flow is usually based on accumulated past experience with tests of many different types of models; flow visualization can be used to verify that the flow at the model/sidewall junction was satisfactory. As the slide valves controlling the suction level cannot (at present) be actively controlled during a wind tunnel run, it is necessary to set a value which is dictated by the most extreme flow condition (highest lift) to be encountered.

The suction level is specified in terms the suction flow velocity normal to the wall relative to the streamwise velocity, the ratio being deduced from measurements of the pressure in the 'suction boxes' on each side of the tunnel. These measurements are made with 100 psi (700 kPa) differential transducers, using Skinner solenoid valves to provide wind-on ambient pressure 'zeros' (pneumatic short circuits) at each incidence step. The suction velocity ratio at each sidewall is calculated from the measured pressures using empirical constants defining the pressure drop across the Rigimesh panels, the constants having been defined originally by a calibration process based upon matching the computed and measured suction box pressures for a given slide valve open area. For most single element airfoils a nominal value of 0.0083 for the ratio 'Vn/Vinf' is judged to be about optimum, while for low Mach number tests of multi-element airfoils in high lift configurations much larger values are required, ranging as high as 0.030 to

0.035. The adequacy of the suction level is probably best judged from oil dot, (or some other form of), flow visualization at the model ends adjacent to the walls, but this is a time-consuming process. Another criterion which has been found quite effective is the extent of agreement between the lift measured by the sidewall balance and that derived from the measured pressure distribution on the model. Here good agreement can be taken as an indication of good spanwise flow uniformity, while a pressure derived value significantly larger than its balance counterpart probably is the result of inadequate sidewall suction.

The ejector system can be used to increase the suction available at test conditions where the test section pressure is low, but its operating envelope as a function of Mach number and stagnation pressure is fairly limited. For test conditions at which the ejectors cannot be operated, but for which the test section pressure is low, it may not be possible to achieve the desired 'optimum' suction.

2.3 Ceiling and Floor Pressure Tubes

The effect of wall constraints on the flow Mach number and model angle of attack are evaluated by the method described in Reference 6. For this measurements of the longitudinal static pressure distributions on the ceiling and floor are required, and these form part of the standard 2-D test operation. Each distribution is obtained from a series of 40 pressure orifices located on a generator of a 1" (25 mm) diameter aluminum tube, and each of the top and bottom walls is equipped with such a tube so that the line of orifices is located at bottom (or top) dead centre of the tube as it is attached to the corresponding wall. The pressure orifices are distributed non-uniformly along the tube and are more concentrated in the vicinity of the model. The pressures are routed through small bore stainless steel tubing within the aluminum tubes to a pressure scanning system based on two multi-module D-9 Scanivalve drives located in the plenum chamber, one on each side of the test section. This system also serves to measure the model static pressure distribution for suitably instrumented models. The wall static pressure measurements are made differentially with respect to the tunnel static reference pressure, utilising 10 psi (70 kPa) range differential transducers.

The ceiling and floor of the 2-D interchangeable test section module were manufactured with integral static pressure orifices distributed along their length in the hope that these would serve for measurement of the required pressure distributions, thus avoiding the need for the less convenient static pressure tubes. However the results obtained during empty tunnel calibrations indicated that the pressures at some of these 'integral' pressure orifices were being adversely influenced by, it is thought, the inclined 'porosity' holes. The measurements were extremely repeatable for multiple scans at a given condition, but the nature of the pressure distribution was greatly inferior to that obtained from the static tubes. As a result the ceiling and floor static pressure tubes continue to form a part of the standard 2-D test section instrumentation. These are mounted with an offset of 4.5" (11 cm) from the tunnel centreline to avoid interference with the variable porosity sliding plates and the 'integral' pressure holes; the offset is toward the north sidewall on the ceiling and the south sidewall on the floor.

3 PREPARATION OF AIRFOIL MODELS

When received by IAR (HSAL), all airfoil models undergo a series of checks in preparation for testing. Initially several measurements are made to ensure that the model will fit into the test section and can be engaged on the balance mounting pins. The key dimensions are the model span and the parallelism of the ends, the diameter of the four mounting holes to suit the balance pins, and the spacing of the hole centres. In addition the pneumatic connectors, which are installed in the ends of models equipped for surface pressure measurement, are checked for correct location and alignment. Information concerning the required tolerances for these items is given in Reference 1. When mounted on the balance pins the model must have some freedom of movement laterally ('float'), usually in the range of 0.015" to 0.020" (0.5 mm), and to achieve this condition spacer 'buttons' are manufactured to the required thickness and inserted in the rear mounting holes. At the two extremes of the 'float' range the model is then restrained by contact between one of the balance mounting pins and the corresponding spacer button; this maintains

adequate clearances between the model and the sidewalls. A special seal design, consisting of spring loaded Teflon pads located in slots in each end of the model, is used to limit flow between the upper and lower surfaces around the ends of the model.

Upon completion of any machining operations which may have been necessary to achieve a proper fit, the pneumatic lines are always flushed with a solvent (alcohol) and checked for leaks or blockages.

4 INSTRUMENTATION

For a majority of 2-D airfoil tests the instrumentation required is fairly standard and falls into two general categories; these relate to 'tunnel' measurements which are required even when no model is present, and 'model' measurements which apply only to an installed model. Figure 5 illustrates the principal test measurements schematically, and they are listed in Table 1.

4.1 'Tunnel-Related' Measurements

The basic test conditions are determined from measurements of the stagnation pressure (P0) at the inlet to the 2-D test section, the test section reference static pressure (P45R or PI) measured at a wall pressure tap located well upstream of the model, and the stagnation temperature (T0) measured in the tunnel settling chamber by a resistance thermometer. The two pressures are measured in an absolute sense using 200 psia (1400 kPa) Paroscientific Digiquartz pressure transducers. However, to eliminate inaccuracies which might result from long term zero drifts, these measurements are reduced as increments from the pre-run, ambient pressure, tare readings, and then converted to absolute values using a high precision measurement of the ambient pressure in the test section (basically atmospheric pressure) made using a 45 psia (300 kPa) Digiquartz unit.

The ceiling and floor static pressure tubes described in Section 2.3 are part of the normal wind tunnel instrumentation for 2-D tests. As previously noted, these static tube pressure distributions are measured on a pressure scanning system consisting of two 48-port Scanivalve D-9 drives. This system is used to measure the model surface pressures also and each drive unit, (one on each side of the tunnel), is equipped with multiple valve/transducer modules. The modules used to measure the static rail pressures, (V2 on the north side of the tunnel and V4 on the south side), are normally equipped with Kulite 10 psi (70 kPa) differential transducers. For reliable operation the fastest rate at which the scanning system should be stepped is 20 ports per second, and this is the rate normally adopted. However, operation at a slower rate can be beneficial to the quality of the data at low Mach and Reynolds numbers, and this option should be considered for test conditions at which adequate run time is available to complete the required model incidence schedule.

The pressure difference between the ceiling and floor at the approximate quarter chord location of the model is measured to provide a real time indication of lift and hence, using an empirical relationship established from past experience, of the wall interference correction to model incidence. In this way a microprocessor can be used to control the model angle of attack to produce approximately the requested corrected angles which would result following reduction of the data. During data reduction the constants in the empirical relation are evaluated using the measured pressure difference and the actual corrections derived from the wall pressure distributions; these can be compared with the values used by the microprocessor controller and changes made if warranted.

Measurement of the suction box pressures as described in Section 2.2 also falls within this general classification of 'tunnel-related' instrumentation. In addition, several other measurements are made on other wind tunnel systems as a matter of routine, for example on components of the Mach number control system for diagnostic use by HSAL staff; such measurements are effectively transparent to normal users of the facility. Table 1 lists the

transducers used for the principal measurements in a typical test. All transducers are bench calibrated prior to the start of a period of 2-D testing, (which normally is comprised of several projects), and are then usually point checked in situ before each project as part of the routine leak check procedure.

4.2 'Model-Related' Measurements

The 'model related' measurements are fairly standard for most 2-D tests and consist of

(a) normal and axial forces and pitching moment sensed by the sidewall mounted balances,

(b) model drag determined from a survey of the total pressure deficit in the airfoil wake, and

(c) model surface static pressure distributions, (for suitably instrumented models).

4.2.1 Balance Measurements

The force and moment measurements utilise a 3-component strain gauge balance mounted in each sidewall; these two balances support the model by means of two mounting pins on each which engage in matching holes machined in the end faces of the model. The balances form part of the model incidence mechanism, both sides being driven using a controller which electronically maintains the same angle at each side. The two 3-component balances thus are interconnected by the model and are calibrated and used as a single 3-component system, with the assumption that the pitching moment carried by each individual balance is the same. With two-dimensional conditions and equal incidence at each side of the model such an assumption is justifiable.

The balance system utilises four flexures to measure normal force and pitching moment, and two flexures to measure axial force, the load capacities of the individual flexure elements being 5000 pounds (22 kN) for normal force and 1000 pounds (4.4 kN) for axial force. Each balance utilises three ungauged stabilizing links to react any lateral load and yawing or rolling moments. Figure 6 illustrates the geometrical layout of the gauged flexures and gives the normal force / pitching moment operational limits of the balance system.

Model incidence may be programmed with considerable flexibility, (step-pause, ramp, pre-position values, or a combination of any or all of these), but normally the step-pause mode is used with the pause duration being determined by the time needed for completion of all measurements at one value of the incidence. The normal mode of operation for 2-D testing is to perform each wind tunnel blowdown at constant freestream conditions, and to gather data at a series of discrete steps of the model incidence. In fact the wind tunnel control system, and the data acquisition and reduction processes, are sufficiently flexible to allow other operational modes, for example variation of Mach number (over a range of approximately 0.2) and/or stagnation pressure (18 psia to 200 psia or approx. 120 to 1400 kPa). However the need to preset the slide valves controlling the amount of sidewall suction, at the moment largely precludes the use of such modes. Future development of the facility will include active control for the sidewall suction system to provide greater operational flexibility.

4.2.2 Wake Drag Measurements

Measurements of the total pressure deficit in the wake are performed using a traversing rake housed in a module located in the test section south sidewall, (Figure 2). The traversing head carries pitot probes located at four spanwise stations, one situated on the test section centreline and the others displaced from centreline by 0.233, 0.467, and 0.700 of the semi-span towards the south sidewall, (drawing C-46609). The probes have an outside diameter of 0.0625" (1.5 mm) and bore of 0.03125" (0.8 mm), and are located so that their measurement station is approximately 21" (53 cm) downstream of the balance centre of rotation; for a 12" (30 cm) chord model this places the measurement station approximately one chord length downstream of the trailing edge. The

relative position of the model and the wake rake, and the spacing of the pitot tubes on the rake, is illustrated in Figure 7. The traverse limits of the wake rake extend between nominal values of 20" (50 cm) above and 10" (25 cm) below the balance centre, although 18" (45 cm) and 8" (20 cm) respectively are more realistic practical limits. The original design concept of the 2-D test section was to provide a facility for high Reynolds number testing at transonic speeds, and accordingly this asymmetric range was chosen to provide adequate coverage of the wake from an airfoil having a shock wave on the upper surface. When testing multi-element airfoils at low Mach numbers and in high lift configurations, it is necessary to mount the airfoil in an inverted attitude in the test section so that the larger upward traverse range is available to capture the highly deflected wake. Within the +20" (+50 cm) and -10" (-25 cm) extremes both the rate and limits of the traverse can be programmed to suit the test conditions. The rate is normally determined by the pause time at the incidence step which, in turn, is a function of the time required to complete a pressure scan; at a typical 20 port per second scanning rate this is approximately 2.5 seconds. The controller also contains a pressure derivative detector which, when selected to be active, serves to reduce the traverse rate in regions of rapidly varying pressure, thus improving the definition of the wake profile in these regions. The normal practice is to have this pressure derivative function active for all tests. The traverse limits may be either fixed or defined to change as functions of the model incidence; with a fixed data sampling rate (100 Hz.) the latter mode can provide better definition of the profile by reducing the extent of the traverse beyond the boundaries of the wake. Incidence function wake limits are normally selected for all tests. The four wake pitot pressures are measured differentially relative to the freestream stagnation pressure (P0) using four 25 psi (175 kPa) Statham differential transducers (W1, W2, W3, W4), with ambient tunnel pressure 'zeros' being recorded before and after each traverse to eliminate or minimise transducer thermal drift effects. This is accomplished by a wafer valve system which switches to apply the local wake pressure (W1 to W4) to both sides of the diaphragm of each transducer to define the tare state. The vertical position of the rake ([illegible] H) is measured using a conductive plastic potentiometer and is recorded as a data channel.

4.2.3 Model Surface Pressure Measurements

Models designed for measurement of surface static pressure distributions can be equipped with a maximum of 80 pressure orifices routed to two HSAL-designed 40-port pneumatic connectors, one located in each end of the model. The model surface pressures are distributed between two of the valve/transducer modules in the pressure scanning system, one on the north side of the tunnel (V1) and the other on the south side (V3). This distribution is dictated by the allocation of the surface orifices to the 40-port pneumatic connectors located in each end of the model, the connector on the left hand side of the model being adjacent to the north side of the tunnel when the model is in an upright position. The connection between the model connectors and the Scanivalve modules is accomplished using special pneumatic harnesses which pass through a 1.5" (38 mm) diameter bore in each sidewall balance and connect with the wing connector. The model surface pressures are measured using Kulite 200 psi (1400 kPa) absolute pressure transducers. Each model requires a 'plumbing table' which defines the pneumatic interconnections between the surface orifice, the port on the wing pneumatic connector, and the Scanivalve port; the relationship between the wing connector ports and the Scanivalve ports is pre-defined by the existing pneumatic harnesses. The co-ordinates of each orifice are also defined in the plumbing table, and this information is used by the data reduction program in integration of the pressure distribution to define the normal force, chord force, and pitching moment coefficients.

As noted in Section 4.1 the pressure scanning system is commonly operated at 20 ports per second. To achieve the necessary pneumatic system response for operation at this rate, great care is taken to minimise the 'transfer volume' when the transducers are installed in the valve modules. It is also important to avoid having any large differences between the pressures on adjacent ports, as there may be insufficient time for the pressure to stabilize if the step is large. This fact should be kept in mind when planning the connection of the surface pressures on the model to the wing pneumatic connectors, and thence to the Scanivalve modules via the pre-defined order of the HSAL pneumatic harnesses. One further point is that any unused ports on a wing connector should never be blocked as this can create trapped volumes and potentially large

pressure steps between ports. At low Mach number and Reynolds number test conditions when the available run time is quite large, the advantage of a slower scanning rate should be considered. However the longer the blowdown the lower the final pressure in the storage tanks, and the longer the time to recharge the tanks for the next run!

5 FLOW VISUALIZATION CAPABILITY

The model surface flow may be visualized, for example by using a fluorescent dye and oil mixture, and the patterns recorded using either video or 35 mm Nikon cameras, (with motor drives), mounted in the wind tunnel floor and/or ceiling. When illuminated with an ultraviolet light source the fluorescent dye emits radiation in the visible spectrum which then can be recorded by conventional black and white or colour photography. The model surfaces are illuminated through ports located in the sidewalls using electronic flash units covered with Kodak 18A UV-passing filters, while the cameras observe the model through ports in the ceiling and floor. To provide the best contrast possible two filters are employed in the receiving optics; a Kodak 2E UV-blocking filter is sandwiched between the glass elements of each camera port, and the camera lenses themselves are equipped with Hoya B-460 filters to reject the infrared emissions passed by the Kodak 2E filter.

The fluorescent oil technique allows the flow pattern at more than a single incidence setting to be recorded during one wind tunnel run, and satisfactory results can be obtained for approximately four different model attitudes. At each incidence the cameras can be programmed to record multiple frames with a prescribed delay between each frame, so that the development of the pattern can be observed. Either 35mm. film or videotape media may be used to record the flow patterns, however the small size of the camera ports does not permit the use of both 35mm. and video cameras at the same time.

Application of the fluorescent dye and oil mixture to the model as an overall coating permits the multiple attitude mode of operation noted above, but has the disadvantage that it is usually necessary to tape over the pressure orifices to prevent ingestion of the oil. In some applications it may be sufficient to apply the oil to the surface in discrete dots covering the region of interest, and this mode of operation will usually yield very detailed information about the flow directions on the surface. However, with the 'dot' technique the amount of fluid on the surface is small, (an advantage in that it is less intrusive), and the flow pattern can only be obtained for a single model attitude. For this reason the technique is more often used with a mixture of either lamp black or titanium dioxide in oil, (whichever will provide the best contrast with the model surface colour), than with the fluorescent dye and oil mixture, as the pattern can then be viewed and photographed under regular lighting conditions following the wind tunnel run.

6 DATA SYSTEM

6.1 System Hardware

In its early form the present wind tunnel data system was built around a Digital Equipment Corporation PDP-11/55 computer, which used software running under the RSX-11M operating system to provide a multi-user time-sharing environment for wind tunnel control and data acquisition, and also data processing and presentation. With the introduction of a VAX 11/785 computer the data processing and presentation function was gradually transferred from the PDP to the VAX, and by 1986 the function of the PDP system, (now using a DEC LSI 11/73 processor), was predominantly that of wind tunnel control and data acquisition. This system is now referred to as the 'tunnel system' as this nomenclature allows for future changes in the particular processor without conflict in existing documentation. Reference 3 provides further description of the data system.

Microprocessors are now used for control of both model attitude and Mach number, thus allowing a great deal of flexibility in operation. For example, the Mach number controller can account (approximately) for solid and wake blockage effects so as to provide the desired value after application of corrections for these effects. The Mach number is usually held constant during a

run, but can be varied according to a specified function if desired. Similarly the model incidence controller can account (again approximately) for wall correction effects by sensing the lift in real time, and evaluating the required correction to incidence from a supplied empirical function.

6.2 Data Acquisition

Data acquisition is controlled by information contained in a 'master data' file which specifies, for each measurement channel, such information as the 2-character channel identification label, amplifier number, sampling rate, amplifier gain, and transducer excitation voltage and calibration factor. The signals from the various measuring devices are amplified and filtered as required, and sampled by the A/D converter at the rate specified by the master data, normally 100 Hz. This rate refers to the frequency at which a scan of all data channels specified in the master data control file is initiated; the data channels are then scanned at a 120 kHz. rate. The digitized data are stored on disk in serial form during the wind tunnel run, then 'sorted' to parallel (channel) form when the run is complete, and stored as separate 'master' and 'run' data files which are identified by the wind tunnel run number. For each run these two files, which are retained on magnetic tape for archival storage, form the data input to the reduction process performed on the VAX computer. Figure 8 shows a schematic diagram of the data acquisition and processing system; this figure is reproduced from Reference 3.

All channels are sampled during the pre-run tare although some of the data acquired at this time are ignored by the data processing software. Examples of measurements for which these pre-run tare data are not required, are the Scanivalve, wake rake, and suction box pressure data; for these channels 'wind-on' ambient pressure tares are used in order to minimise the effects of transducer temperature and case pressure drifts. For the sidewall balance channels pre-run tare data are acquired at three values of the incidence, (typically -20, 0, and 20 degrees), in order to 'weigh' the model and the metric parts of the balance. These data are processed by the method described in Reference 7 to provide the distribution of the tare weight in the balance components as a function of the model incidence.

The philosophy in data acquisition has been to scan all channels continuously during the 'take data' state, and then determine which data samples are valid based upon special 'status information' channels. For example when pressure scanning at a typical 20 ports per second, the Scanivalve unit performs as a pneumatic switch sequentially sampling the 48 pressures connected to it. During the scan approximately 250 data samples will be acquired at a 100 Hz. rate, but perhaps only some 50% of these will be appropriate to stable 'on port' conditions; it is the function of the status information to identify the valid data. Generally each different measurement type has a status channel associated with it; for example pressure scanning, (a separate status for each Scanivalve drive to allow for asynchronous operation), wake rake, model incidence, and suction box pressure measurements all have independent status functions defined by the basic logic task controlling the data acquisition.

The data acquisition software allows the data recorded during a run to be separated into different 'sections'. These 'section' subdivisions can be used to provide a logical separation of the data recorded during the run when, for example, multiple test conditions occur within one blowdown. While this is not a common operational mode at the present time, (because of the requirement to preset the sidewall suction level for one test condition), it can still be used to advantage for some test conditions. A maximum of eight 'sections' of wind-on data are permitted, and the data processing is automatically performed on a section-by-section basis. The 'section' subdivisions are retained in the tabulation of the reduced data.

The 'standard' measurements for a 2-D test would normally consist of the 26 data channels indicated in Table 1, with additional channels being recorded to monitor various wind tunnel systems for diagnostic use. Table 2(a) shows a listing of a sample master data file; in addition to information required by the acquisition programs, (not all of which appears in the listing), this file also contains information about the model and the test set up for each run, which is used in the data reduction process. This information is divided into three categories, namely 'alphanumeric', 'integer', and 'real' data types, which are described more fully in Table 2(b). All data channels are normally sampled 100 times per second. The steady state model measurements

are low-pass filtered to a 3 Hz. cutoff frequency, while the filter settings for the scanned pressure and the wake rake measurements are set at 30 Hz. and 10 Hz. respectively; these latter settings are standard and have been selected to be compatible with the dynamics of the associated pressuring measuring systems.

7 DATA ACCURACY

The accuracy of a computed data quantity depends upon the accuracy of measurements of the basic parameters used in deriving that quantity. This, in turn, depends in large part on the accuracy of the instrumentation, (amplifiers, transducers, A/D converters, etc.), used in making the basic measurements, and of these components it is the accuracy of the transducer itself which normally predominates. Figures for the approximate expected accuracy of the principal measurements of a normal 2-D test are given below; the two-character labels noted for each measurement are defined in Table 1.

'Tunnel' pressures, (P0, PI, PA)	: +/- 0.005 to 0.010 psi (0.035 to 0.07 kPa)
Stagnation temperature (T0)	: +/- 1 degree Rankine
Model incidence (IN, IS)	: +/- 0.03 degrees
Model surface pressures (V1, V3)	: +/- 0.10 psi (0.7 kPa)
'Wake' pressures (W1, W2, W3, W4)	: +/- 0.01 psi (0.07 kPa)
'Wall' pressures (V2, V4)	: +/- 0.005 psi (0.035 kPa)
Balance normal forces (N1, N2 S1, S2)	:+/-0.1%FS(+/-5lb or 22N)
Balance axial forces (X1, X2)	: +/- 0.1%FS (+/- 1lb or 4.4N)

These figures are based on the transducer manfacturer's specification for accuracy, (e.g. 0.05% to 0.1% of full range is typical of the transducers used in the pressure scanning and wake rake systems), with consideration also being given to the linearity and hysteresis indicated by the individual calibration results. The figures generally indicate the 'limits of accuracy', and the probable 'uncertainty' in a measurement will normally be considerably smaller. The lower accuracy figure noted for the model pressures as compared to the wall pressures results from the fact that the former are measured using 200 psi (1400 kPa) range absolute pressure transducers, and the latter using 10 psi (70 kPa) differential pressure transducers. The probable maximum range of the error in a derived quantity can be estimated using the stated transducer accuracy figures for each measurement used in the derivation, with these errors being propagated through the computations according to the equations noted in Appendix A. With such an approach the figures represent situations in which all error components combine in the most adverse manner possible, and generally actual measurement uncertainties will be substantially smaller.

In addition to the relatively well-defined instrument accuracy, the overall uncertainty of a measurement will be affected by the stability and repeatability of control systems and the steadiness of the wind tunnel flow itself. Thus the repeatability of data provides another measure of its quality, as it reflects the stability and noise level characteristics of both the instrumentation and the control systems, and also the flow quality in the wind tunnel itself. Based on results obtained in a specific recent investigation, the data repeatability can be summarised by the standard deviations for the quantities noted below:

a)	Mach number	- 0.0006
b)	Stagnation pressure	- 0.02 psi (0.14 kPa)
c)	Static pressure	- 0.02 psi (0.14 kPa)
d)	Dynamic pressure	- 0.015 psi (0.1 kPa)
e)	Model incidence	- 0.015 deg.
f)	Balance normal force	- 0.004
g)	Balance axial force	- 0.002
h)	Balance pitching moment	- 0.0005
i)	Integrated pressure normal force	- 0.004
j)	Integrated pressure axial force	- 0.001
k)	Integrated pressure pitching moment	- 0.0007
l)	Average wake drag	- 0.0002 to 0.0006

(The quantities noted under 'f' to 'l' above are all in non-dimensional coefficient form).

A range is indicated for the average wake drag, the lower value corresponding to measurements with fixed transition and the higher one to those with natural transition when the transition front is less uniform in a spanwise sense, leading to a somewhat larger deviation. The small dispersion of the force and moment coefficients derived from integration of the surface pressure distributions implies good repeatability of the measured surface pressures also.

8 DATA PROCESSING

All data reduction and plotting of requested parameters is performed, using the VAX 11/785 computer, immediately following completion of each blowdown. The amount of time required for this task depends upon the volume of data acquired in the run, (i.e. number of incidence steps programmed), but typically tabulated data printouts are available within 5 - 10 minutes, and the plotted data shortly thereafter.

No detail is provided here in regard to manipulation of the raw data to form valid data point averages, (or scanned pressure port averages), based upon the various status signals, nor conversion of these averages to engineering units using information contained in the master data file. However, the basic equations used in reducing the data to the form given in the tabulated output are described in Appendix A. Because of the very similar nature of all 2-D airfoil tests the data reduction program and the tabular output formats have been standardized.

A correction is normally applied to the measured reference static pressure (P45R) to compensate for the calibrated difference between it and the centreline static pressure obtained during the empty tunnel calibration. The correction is expressed as a pressure coefficient referenced to the centreline static pressure as noted in Appendix A. For the original 2-D test section the coefficient value was 0.0275, but for the present 2-D configuration the reference and centreline static pressures were found to be the same, corresponding to a zero value for the coefficient. The correction algorithm is always applied in data reduction, but a flag is set at execution time to specify which of these two coefficient values should be used, thus allowing for processing data from either the original or the new test section.

A correction to model incidence is applied to compensate for upflow in the tunnel, established during calibration by tests with a model mounted in both upright and inverted attitudes. Flow angle measurements were made for different settings of the ceiling and floor porosity, (2%, 3%, and 4%), and the flow direction was found to be somewhat Mach number dependent in each case. The Mach number functions used in the data reduction are indicated in Appendix A.

Finally all data are corrected for wall interference effects by applying the Mach number and angle of attack corrections computed from the ceiling and floor pressure distributions by the method of Reference 6. The effect of the Mach number change on both the static and dynamic pressures is accounted for in correcting the force, moment, and pressure coefficients. The model angle of attack is also corrected for wall interference, and the wind-axis coefficients are determined using the resulting corrected angle.

The force and moment data, in coefficient form, obtained from the sidewall balance, surface pressure distribution, and wake drag measurements are presented together in one of the standard output formats, which is illustrated in Table 3. This table shows the format for a multi-element airfoil model, and was chosen to illustrate the presentation of the force and moment coefficients for the individual elements as well as the 'summed' coefficients for the complete configuration. These latter take into account any translations and rotations of the subsidiary elements with respect to the main element which were defined in the master data. The data reduction software permits up to four model elements. The pagination of this form of output is determined from the 'section' sub-divisions implemented at the time the data were acquired; normally each section, and thus each page of output, will contain 10 or fewer data points.

The model pressure coefficient data are presented in another standard format, as illustrated in Table 4. In this case each page contains the data for a single pressure scan (incidence step). The pressure coefficients are listed in the order in which they are defined by the plumbing table, with the data for each element of a multi-element model, (i.e. 'pressure set') being listed

separately. When the pressure distributions are to be integrated to provide normal force, chord force and pitching moment, the pressure coefficient listing will follow a counter-clockwise progression around the airfoil commencing at the trailing edge, as required by the sign convention used in the integration subroutine.

Selected variables may be presented in graphical form, and it is normal to plot the variations of lift, drag, and pitching moment coefficients with incidence and/or drag coefficient. Both balance and 'pressure derived' force and moment coefficients may be plotted, and for the lift coefficient there should be quite good agreement between the two; in fact this is a reasonable criterion for assessing the spanwise uniformity of the flow. For drag coefficient however, only the wake traverse results can be relied upon. The model surface pressure distributions are also plotted as a function of 'x/c' on a routine basis, and can readily be plotted as a function of 'z/c' also if desired. Indeed it is possible to plot almost any of the normally available variables against any other variable. The plotting software is based on GKS, (Graphical Kernel System), and uses a format which is essentially the same for all plot types, with the "X" and "Y" variable selection and scaling specifications being made with entries in a 'plot control file'. Figure 9 shows samples of the format used for plotting force and moment coefficients, illustrated by plots of C_L/α and C_L/C_D. Figures 10 and 11 show, respectively, plots of the surface pressure distributions on the model, and the ceiling and floor static pressure tubes. For these pressure distribution plots the GKS plot format displays the data for all scans within a 'section' on the same page, using different symbols and line types. Figure 12 shows plots of the wake C_D' vs h/c profiles, the function C_D' being defined in Appendix A.

For Figures 10 to 12 two alternative formats are shown, the "(b)" figure in each case illustrating a display which is intended for diagnostic purposes rather than data interpretation. These quick-look displays are generated by in-house graphics software and because of their simplicity can be produced more quickly than the GKS plots. They provide a very adequate, and in some cases preferable, format for validating the ceiling and floor pressure data, and the wake rake pressure measurements and range of traverse.

Following completion of the project the accumulated reduced data files, which are organized as structured binary files on the HSAL computer system (VAX), are converted to an ASCII sequential format and written to a magnetic tape which will be readable by any computer system. The organization of the data on the tape is described in Reference 8.

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TABLE 1

CHANNEL NUMBER	CHANNEL LABEL	PARAMETER DESCRIPTION	NOTATION USED	PRESSURE TRANSDUCER OR OTHER MEASURING DEVICE
1	TM	Run sequence elapsed time		Computer clock
3	PO	Stagnation pressure	PT1	Digiquartz 200 psia
7	PI	Reference static pressure	P45R	Digiquartz 200 psia
9	PA	Atmospheric pressure	Patm	Digiquartz 45 psia
13	TO	Stagnation temperature	T0	RdF probe
14	N1	Fwd. normal force)	N1	North side
15	N2	Aft normal force) NORTH	N2	3-component
16	XN	Axial force)	Xn	balance
17	S1	Fwd. normal force)	S1	South side
18	S2	Aft normal force) SOUTH	S2	3-component
19	XS	Axial force)	Xs	balance
20	MS	Master status (word contains eight 2-bit encoded values)		
21	IN	North balance incidence	IN	North potentiometer
22	IS	South balance incidence	IS	South potentiometer
23	V1	Wing surface pressures	Pwing	Kulite 200 psia
24	V2	Ceiling static pressures	Pceil	Kulite 10 psid
25	V3	Wing surface pressures	Pwing	Kulite 200 psia
26	V4	Floor static pressures	Pfloor	Kulite 10 psid
27	SN	North suction box pressure	Psbn	Kulite 100 psid
28	SS	South suction box pressure	Psbs	Kulite 100 psid
29	WH	Wake probe height	Hrake	Potentiometer
30	W1	Centreline wake probe (#1)	PTw1	Statham 25 psid
31	W2	Wake probe #2	PTw2	Statham 25 psid
32	W3	Wake probe #3	PTw3	Statham 25 psid
33	W4	Wake probe #4	PTw4	Statham 25 psid
43	FC	(Ceiling-Floor) pressure difference for real time Mach number control		Kulite 10 psid

Notes: (1) Pressure differences for the ceiling and floor tubes and the suction box measurements are referenced to P45R.

(2) Pressure differences for the wake probe measurements are referenced to the tunnel stagnation pressure (PT1S).

(3) The CHANNEL NUMBER assignments may vary from test to test; the assignment shown corresponds to the master data listing shown in Table 2(a).

TABLE 1: MEASURED PARAMETERS AND ASSOCIATED INSTRUMENTATION DEVICES COMMON TO THE DATA REQUIREMENTS OF MOST 2-D AIRFOIL TESTS.

TABLE 2(a)

MASTER DATA dd-mmm-yy hh:mm:ss RUN #####

	PO	PI	TO	M	Q	R
3 BLOCKS	37.98	32.01	527.5	0.500	5.61	8.06
62 CHANNELS	0.11	0.44	28.2	0.021	0.39	0.77

PI SWITCHES: 0

PRETARE: 132 132 STARTUP: 212 466
WINDON: 2466 4441 6890 6890 6890 6890 6890 6890
SHUTDOWN: 6890 6890 POSTTARE: 6890 6890

12 ALPHANUMERIC MASTER DATA:

##### dd-mmm-yy hh:mm:ss	PROJECT IDENTIFICATION
<------- HEADER LINE 1A ------->	<------- HEADER LINE 1B ------->
<------- HEADER LINE 2A ------->	<------- HEADER LINE 2B ------->
<------- HEADER LINE 2C ------->	SM
0.002 0.235 0.469 0.702	123
MAIN-FLAP MISC RAIL RAIL	PLUMBING TABLE FILENAME
NOAV NOAV	0001

30 INTEGER MASTER DATA:

2	48	20	2	48	20	-1	50	0	2
4	13	29	47	99	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

32 REAL MASTER DATA:

0.00000E+00	3.0000	0.00000E+00	0.00000E+00	0.00000E+00
15.000	7.5600	-0.23400	2.1921	-0.13100E-01
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	3.0000	0.00000E+00	0.00000E+00	0.00000E+00
12.000	1.9500	0.10000	0.00000E+00	0.50000E-02
0.50000E+00	0.30000E+00			

CHANNEL PARAMETER DATA:

		CHAN	CLK	CALIBR	ZERO	VEX		GAIN	FLTR	PS	DIN
1	TM	142	13	0.465661E-03	0.00000E+00	1.0000	TM	1.000	0	77	0
2	--	143	0	30.5176	0.00000E+00	1.0000	--	1.000	0	77	0
3	PO	4044	0	30.5176	0.00000E+00	1.0000	PO	1.000	0	77	6206
4	--	4045	0	0.200000E+07	0.00000E+00	1.0000	--	1.000	0	77	0
5	PN	4040	0	30.5176	0.00000E+00	1.0000	PN	1.000	0	77	6203
6	--	4041	0	0.200000E+07	0.00000E+00	1.0000	--	1.000	0	77	0
7	PI	4046	0	30.5176	0.00000E+00	1.0000	PI	1.000	0	77	6207
8	--	4047	0	0.200000E+07	0.00000E+00	1.0000	--	1.000	0	77	0
9	PA	4052	0	30.5176	0.00000E+00	1.0000	PA	1.000	0	77	6040
10	--	4053	0	0.200000E+07	0.00000E+00	1.0000	--	1.000	0	77	0
11	D2	4062	0	30.5176	-0.36163E-02	1.0000	D2	1.000	3	77	6200
12	--	4063	0	0.200000E+07	0.00000E+00	1.0000	--	1.000	3	77	0
13	TO	32	0	1.11111	532.40	1.0000	TO	50.00	3	77	0
14	N1	0	0	0.400396E-03	81.198	7.5000	N1	1000.	3	20	0
15	N2	1	0	0.406729E-03	154.67	7.5000	N2	1000.	3	20	0
16	XN	2	0	0.119862E-02	37.105	7.5000	XN	2000.	3	20	0
17	S1	3	0	0.417414E-03	-57.806	7.5000	S1	1000.	3	20	0
18	S2	4	0	0.409354E-03	-49.601	7.5000	S2	1000.	3	20	0
19	XS	5	0	0.120298E-02	-3.8560	7.5000	XS	2000.	3	20	0
20	MS	167	0	0.000000E+00	0.00000E+00	1.0000	MS	1.000	3	77	0

TABLE 2(a) concl.

21	IN	6	0	83.0630	-0.91843E-02	1.0000	IN	1.000	3	77	0
22	IS	7	0	82.8460	0.13505E-01	1.0000	IS	1.000	3	77	0
23	V1	10	0	0.680500E-01	-5.3598	5.0000	V1	100.0	30	23	1018
24	V2	11	0	0.974053	0.96498E-01	5.0000	V2	50.00	30	23	2033
25	V3	12	0	0.648350E-01	-7.4210	5.0000	V3	100.0	30	3	1016
26	V4	13	0	0.716284	0.10396	5.0000	V4	50.00	30	3	2038
27	SN	20	0	0.106386	1.5031	10.000	SN	50.00	3	10	2112
28	SS	21	0	0.850130E-01	0.17231	10.000	SS	50.00	3	2	2110
29	WH	23	0	200.000	-0.26000E-01	1.0000	WH	1.000	10	77	0
30	W1	24	0	91.9151	0.12617	5.0000	W1	1.000	10	0	2524
31	W2	27	0	77.4940	-1.5091	5.0000	W2	1.000	10	0	2528
32	W3	26	0	104.791	0.29355	5.0000	W3	1.000	10	0	2521
33	W4	25	0	95.0110	-0.96360E-02	5.0000	W4	1.000	10	0	2522
34	4W	15	0	0.186744	-0.98052E-02	5.0000	4W	500.0	30	0	2522
35	TF	40	0	200.000	0.00000E+00	1.0000	TF	1.000	10K	0	0
36	TR	42	0	200.000	0.00000E+00	1.0000	TR	1.000	10K	0	0
37	BF	44	0	200.000	0.00000E+00	1.0000	BF	1.000	10K	0	0
38	BR	46	0	200.000	0.00000E+00	1.0000	BR	1.000	10K	0	0
39	R1	260	0	2.00000	0.00000E+00	1.0000	R1	1.000	3	0	0
40	R2	262	0	2.00000	0.00000E+00	1.0000	R2	1.000	3	0	0
41	R3	264	0	2.00000	0.00000E+00	1.0000	R3	1.000	3	0	0
42	R4	266	0	2.00000	0.00000E+00	1.0000	R4	1.000	3	0	0
43	FC	31	0	0.262032	-1.1404	5.0000	FC	500.0	3	22	2051
44	PW	33	0	0.588794	0.30476	5.0000	PW	100.0	30	21	2049
45	CV	230	0	500.000	-0.27771	1.0000	CV	1.000	0	77	0
46	TP	231	0	30.0000	-0.73717	1.0000	TP	1.000	0	77	0
47	NP	236	0	100.000	-1.1727	1.0000	NP	1.000	0	77	0
48	SP	237	0	100.000	-1.5908	1.0000	SP	1.000	0	77	0
49	PS	247	0	0.820000E-02	-23.524	5.0000	PS	500.0	0	77	0
50	LF	224	0	41.6660	-10.194	1.0000	LF	1.000	0	77	0
51	UF	225	0	41.6660	-10.194	1.0000	UF	1.000	0	77	0
52	BP	232	0	0.163400	-7.0795	5.0000	BP	100.0	3	4	2526
53	MU	4110	0	4885.20	0.00000E+00	1.0000	MU	1.000	0	77	0
54	MC	4100	0	4885.20	0.00000E+00	1.0000	MC	1.000	0	77	0
55	QU	4102	0	152.588	0.00000E+00	1.0000	QU	1.000	0	77	0
56	ME	4112	0	4885.20	0.00000E+00	1.0000	ME	1.000	0	77	0
57	TW	4212	0	1.00000	0.00000E+00	1.0000	TW	1.000	0	77	0
58	CL	4220	0	1000.00	0.00000E+00	1.0000	CL	1.000	0	77	0
59	IC	4216	0	166.666	0.00000E+00	1.0000	IC	1.000	0	77	0
60	CC	4217	0	166.666	0.00000E+00	1.0000	CC	1.000	0	77	0
61	IU	4215	0	166.666	0.00000E+00	1.0000	IU	1.000	0	77	0
62	RW	260	0	0.588794	-0.96405E-02	5.0000	RW	1000.	30	21	2049

NOTE:
=====

This listing shows the data channels recorded in one particular 2-D test, and includes many channels which are used exclusively by HSAL personnel for monitoring various wind tunnel systems. Those channels associated with measurements which are common to a majority of 2-D airfoil experiments are noted in Table 1.

TABLE 2(a): SAMPLE OF THE MASTER DATA FILE LISTING FORMAT

TABLE 2(b)

TYPE	LINE #	DESCRIPTION
A	======	ALPHANUMERIC data =================
A	1-5	Notes on model configuration, test conditions, etc. for output in the tabulated data listings.
A	6	not used.
A	7	Wake probe locations w.r.t. tunnel centreline as fractions of the test section semi-width.
A	8	Identification of the probes to be included in the averaged wake drag.
A	9	Type definition of each "pressure set" in the plumbing table as:- MAIN: the primary, or only, element of the airfoil \ Pressures in SLAT: any secondary leading element of the airfoil | these sets to FLAP: any secondary trailing element of the airfoil / be integrated. MISC: miscellaneous pressures to be computed but not integrated. RAIL: designates the ceiling and floor "static tube" pressures. DUMY: used to totally ignore a pressure set in the plumbing table.
A	10	Name of the "plumbing table" file.
A	11	Flag defining treatment of the trailing edge pressures in integrations of the model surface pressure distributions. Pressure coefficients for the upper and lower surfaces at the trailing edge ,(CpTEu and CpTEl), are established, either from measurements or from linear extrapolation of the two most downstream measured values on each surface, and then treated as follows:- NOAV: The values "CpTEu" and "CpTEl" are used exactly as determined. AVGD: An average of "CpTEu" and "CpTEl" is used in both locations. UPPR: The value "CpTEu" is used in both locations. LOWR: The value "CpTEl" is used in both locations.
A	12	Definition of status bits for N and S Scanivalve drives.
I	======	INTEGER data ============
I	1	Number of valve modules \
I	2	Number of ports on each module) - for the NORTH Scanivalve drive.
I	3	Drive stepping rate /
I	4-6	Same information as I1 to I3, but for the SOUTH Scanivalve drive.
I	7	Model attitude flag: UPRIGHT = +1, INVERTED = -1.
I	8	Percentage extension of the wake width used, in conjunction with R30, to define the limits of integration for wake drag.
I	9	A flag value controlling production of plots of wall interference corrections to Mach number and incidence - (1 = plot, 0 = no plot)
I	10	Number of Scanivalve drives
I	11	Total number of "duff" pressure orifices, i.e. orifices listed in the plumbing table which are to be ignored in the integration.
I	12-??	Identification numbers for all "duff" pressure orifices.
R	======	REAL data =========
R	1	Angle of the original reference chord of the extended, (or deflected), airfoil element w.r.t. the preceeding element. Trailing edge down is positive for "flap" elements, leading edge down for "slat" elements. This quantity for the "main" (or only) element, and also for the "summation" of all elements, (i.e. R21 = 0.0), equals "0.0".
R	2	The "X" co-ordinate of the element's moment reference point defined in an axis system along and normal to the original airfoil chord, (i.e. all elements retracted), with origin at the leading edge.

TYPE	LINE #	DESCRIPTION
R	======	REAL data (cont.) =================
R	3	The "Z" co-ordinate of the element's moment reference point in the same axis system described under R2.
R	4	The shift in the "X" co-ordinate of the element's moment reference point when the element is deflected or extended. Defined w.r.t. the deflected reference chord axis of the preceeding element. This quantity for the "main" (or only) element, and also for the "summation" of all elements, (i.e. R24 = 0.0), equals "0.0".
R	5	The shift in the "Z" co-ordinate of the element's moment reference point when the element is deflected or extended. Defined w.r.t. the deflected reference chord axis of the preceeding element. This quantity for the "main" (or only) element, and also for the "summation" of all elements, (i.e. R25 = 0.0), equals "0.0".
R	6-10	Same information as contained in R1 - R5, but for element # 2.
R	11-15	Same information as contained in R1 - R5, but for element # 3.
R	16-20	Same information as contained in R1 - R5, but for element # 4.
R	21-25	Same information as contained in R1 - R5, but for the "summation" of the individual element forces and moments.
R	26	Model chord length (inches).
R	27	The "X" co-ordinate of the model moment reference point w.r.t. to the centre of resolution of the balance, positive when the reference point is ahead of the balance centre.
R	28	The "Z" co-ordinate of the model moment reference point w.r.t. to the centre of resolution of the balance, positive when the reference point is below the balance centre.
R	29	Angle (ALBAR) between the chord and the line through the centres of the mounting pin holes, positive nose-up.
R	30	Cut-off level of the coefficient "Cd'" used in determination of the wake integration limits, (in conjunction with I8).
R	31	Nominal angular increment between data points for runs utilising continuous motion incidence variation.
R	32	Angular range for data averaged to form a single data point in runs utilising continuous motion incidence variation.

TABLE 2(b): DESCRIPTION OF THE 'ALPHANUMERIC', 'INTEGER', AND 'REAL' DATA ENTRIES IN THE MASTER DATA FILE.

TABLE 3

```
*****************************************************************************
* NRC IAR                                                           OTTAWA *
*                       <--- PROJECT IDENTIFICATION --->                    *
*                        FORCE & MOMENT DATA - CORRECTED                    *
* 15" X 60" 2-D                                               TEST SECTION *
*****************************************************************************


RUN# / SECT#   <------- HEADER LINE 1A -------><------- HEADER LINE 1B ------->   RUN DATE: dd-mmm-yy
                                                                                  COMPUTED: dd-mmm-yy
STEP MOTION PHASE  #                                                                  TIME: hh:mm:ss
<------- HEADER LINE 2A -------><------- HEADER LINE 2B -------><------- HEADER LINE 2C ------->

   M    REC/RFT (M)  PO(PSIA)  PI(PSIA)  Q(PSI)  TO(DEG R)  V/U(N)  V/U(S)  V/U(A)    KO      K1
 X.XXX  XX.XX/XX.XX   XXX.XX    XXX.XX    XX.XX   XXX.X     X.XXXX  X.XXXX  X.XXXX  X.XXXX  X.XXXX
<----------------- average test condition parameter values for this SECTION of data ----------------->


TUNNEL . . . . . . . . . . . . . . . . . . . . . . BALANCE . . . . . . . . . . . . . . . . .
 DP  ALPHA/ALPHAC    M/MCOR      PO      PI      Q       CN      CX     CM-C/4    CL      CD      DP
        (DEG)        (DEG)     (PSIA)  (PSI)
  1  XX.XX/ XX.XX  X.XXX/X.XXX  XXX.XX  XXX.XX  XX.XX  X.XXX  X.XXXX  X.XXXX   X.XXX  X.XXXX    1
  .                                                                                            .
  .     model angle of attack, test condition parameters, and sidewall balance force and moment  .
  .                  coefficients for each "step" in this SECTION of data                      .
  .                     (number of "steps" per SECTION normally <= 10)                          .
  .                                                                                            .


       WAKE RAKE . . . . . . . . . . .                            DEVIATION FROM AVERAGE . . . . .
 DP    CDW1     CDW2     CDW3     CDW4      CDW AVG    CLB/CDW     DCDW1    DCDW2    DCDW3    DCDW4   DP
      0.000    0.233    0.467    0.700      Prb.123
       distance of probes from centreline (x "b/2"), and probes used to form the AVERAGE drag value
  1  X.XXXX   X.XXXX   X.XXXX   X.XXXX     X.XXXX      XX.X      X.XXXX   X.XXXX   X.XXXX   X.XXXX    1
  .                                                                                                .
  .       individual probe drag coefficients, AVERAGE value from specified probe numbers, and       .
  .                 deviations of each individual value from the AVERAGE                            .
  .                                                                                                .
  .                                                                                                .
  .                                                                                                .


       PRESSURE INTEGRATION - TOTAL . . . . . .       MACH NO. CONTROL       PRESSURE ELEMENT 1 . .
 DP     CN      CX     CM-C/4      CL      CD        MCORR    CP(C-F)       CN(1)    CX(1)    CM(1)   DP
  1   X.XXX   X.XXXX   X.XXXX    X.XXX   X.XXXX     X.XXXX   X.XXXX        X.XXX   X.XXXX   X.XXXX   1
  .                                                                                                .
  .     total force and moment coefficients obtained by integration of the surface static pressure   .
  .     distribution on the model, or for a multi-element model the SUMMATION of the coefficients   .
  .           for all elements, plus the data for the first of the individual elements              .
  .                                                                                                .
  .     also, the measured MACH number control parameter, ("ceiling - floor" pressure coefficient), .
  .            and the calculated (post-run) wall interference correction to Mach number            .
  .                                                                                                .


       PRESSURE ELEMENT 2 . .          PRESSURE ELEMENT 3 . .          PRESSURE ELEMENT 4 . .
 DP    CN(2)    CX(2)    CM(2)         CN(3)    CX(3)    CM(3)         CN(4)    CX(4)    CM(4)    DP
  1   X.XXX   X.XXXX   X.XXXX         X.XXX   X.XXXX   X.XXXX         X.XXX   X.XXXX   X.XXXX    1
  .                                                                                              .
  .      force and moment coefficients obtained by integration of the surface static pressure     .
  .                 distributions for the individual model elements 2 ... 4                       .
  .                                                                                              .
  .                                                                                              .

                                                                                       RUN# / SECT#
```

TABLE 3: "FORCE AND MOMENT COEFFICIENT" DATA TABULATION FORMAT

TABLE 4

```
**************************************************************************************
* NRC IAR                                                                   OTTAWA *
*                       <--- PROJECT IDENTIFICATION --->                           *
*                          WING PRESSURE DATA - CORRECTED                          *
* 15" X 60" 2-D                                                       TEST SECTION *
**************************************************************************************


RUN# / SECT#   <-------- HEADER LINE 1A --------><-------- HEADER LINE 1B -------->   RUN DATE: dd-mmm-yy
SCAN    #                                                                             COMPUTED: dd-mmm-yy
STEP MOTION PHASE  #                                                                  TIME: hh:mm:ss
<-------- HEADER LINE 2A --------><-------- HEADER LINE 2B --------><-------- HEADER LINE 2C -------->


   M     REC/RFT (M)   ALPHACL    PO       PI       Q      CPCRIT    CPSTAG   SUCTION CP  N/S     V/U
 X.XXX   XX.XX/XX.XX    XX.XX   XXX.XX   XXX.XX   XX.XX    XX.XXX    X.XXX    XX.XXX/ XX.XXX   X.XXXX
<-- model angle of attack and average test condition parameter values for this SECTION & SCAN of data -->


ORIFICE   X/C     Y/C     CP     P/PO   M LOCAL   ORIFICE   X/C     Y/C     CP     P/PO   M LOCAL
 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX
   .
   .     orifice label, co-ordinates along and normal to the chord line, local pressure coefficient,
   .     local pressure ratio, and local Mach number for model pressure SET #1
   .
   .     the composition of the pressure set, and the order in which the data in a set are presented,
   .     are defined by the "plumbing table" in use, but will normally be in a counter-clockwise
   .     direction around the airfoil (or element) commencing at the "trailing edge" location on the
   .     upper surface
   .
   .     the total number of model pressure orifices for all model elements is normally restricted to
   .     80 by the complement of the two 40-port pneumatic connectors installed in the model ends
   .
 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX

 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX
   .
   .     orifice label, co-ordinates along and normal to the chord line, local pressure coefficient,
   .     local pressure ratio, and local Mach number for model pressure SET #2 if present
   .
 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX

 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX
   .
   .     orifice label, co-ordinates along and normal to the chord line, local pressure coefficient,
   .     local pressure ratio, and local Mach number for model pressure SET #3 if present
   .
 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX

 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX
   .
   .     orifice label, co-ordinates along and normal to the chord line, local pressure coefficient,
   .     local pressure ratio, and local Mach number for model pressure SET #4 if present
   .
 label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX     label   X.XXX   X.XXX   X.XXX   X.XXX   X.XXX


            CNP(1) = X.XXX         CXP(1) = X.XXXX         CMREF(1) = X.XXXX
                 .                      .                        .
            force and moment coefficients obtained by integration of the surface static
             pressure distributions for the individual model elements (maximum = 4)


                                                                              RUN# / SECT#
```

TABLE 4: 'MODEL PRESSURE COEFFICIENT' DATA TABULATION FORMAT

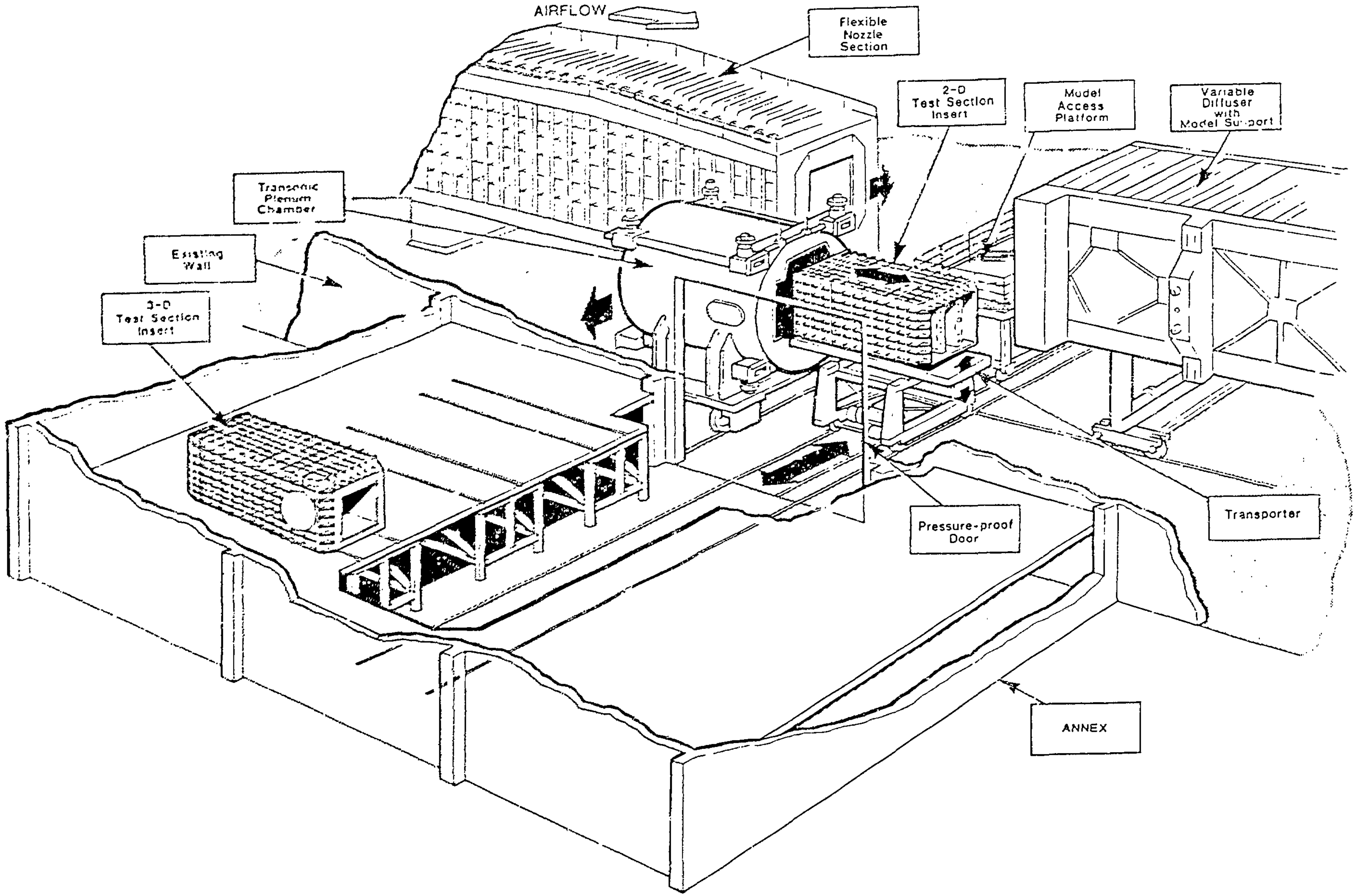
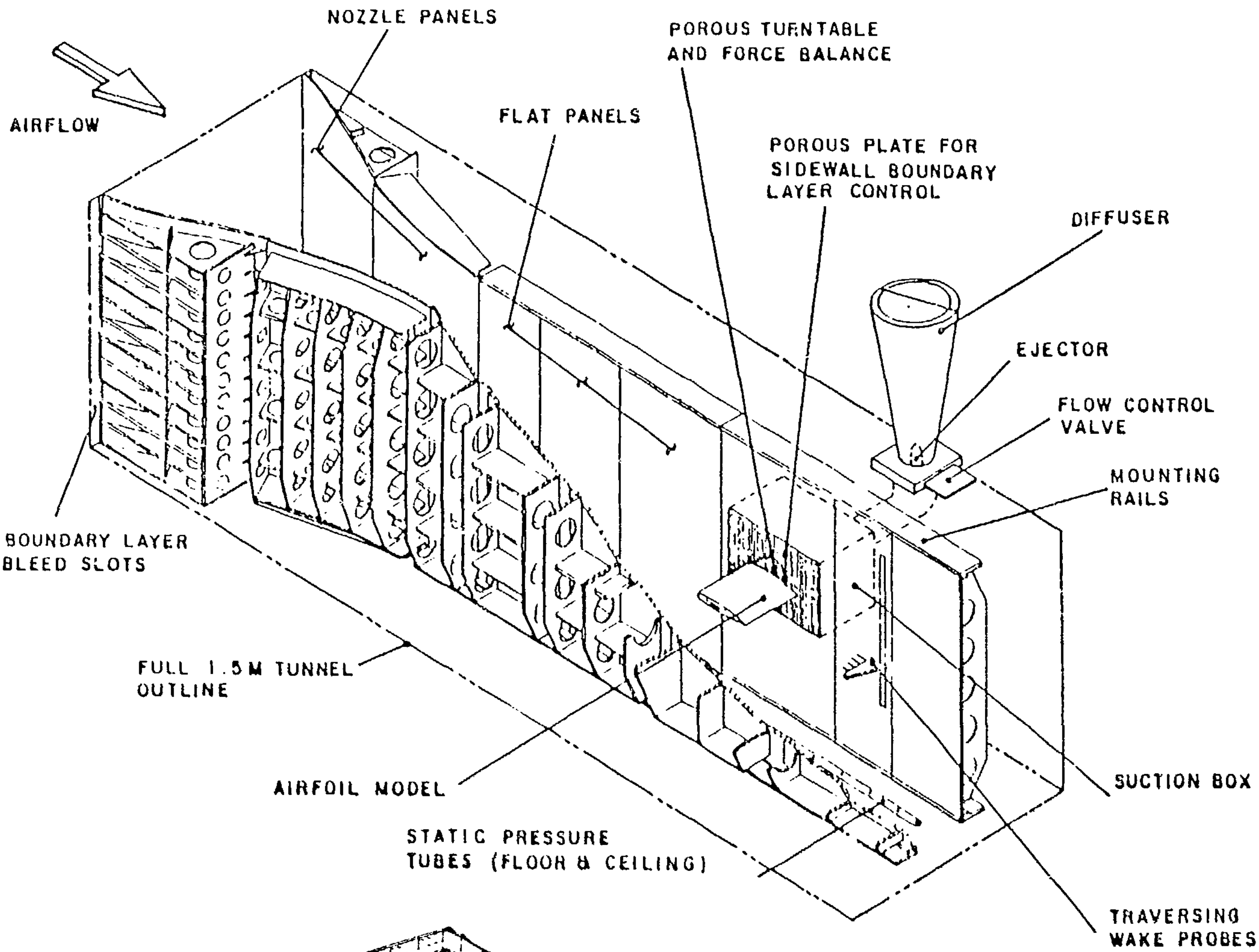


FIG. 1: THE "INTERCHANGEABLE TEST SECTION MODULE" CONCEPT FOR THE IAR 1.5m TRISONIC BLOWDOWN WIND TUNNEL



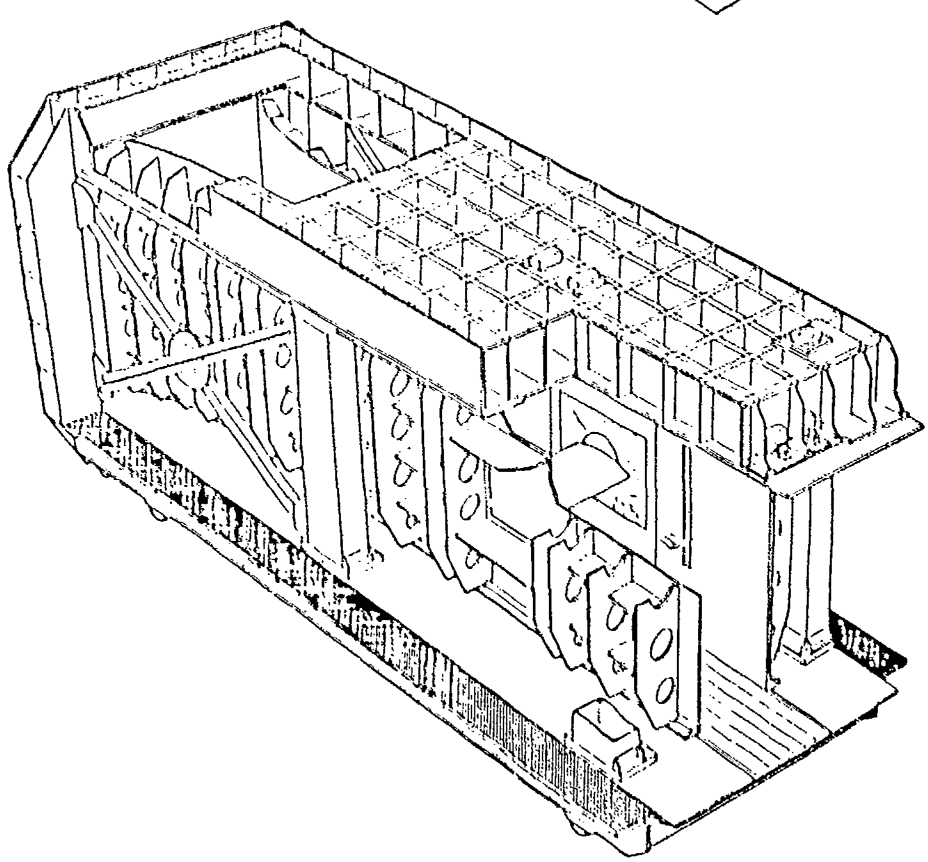


FIG. 2: CUTAWAY VIEWS OF THE INTEPCHANGEABLE 2-D MODULE SHOWING THE PRINCIPAL COMPONENTS

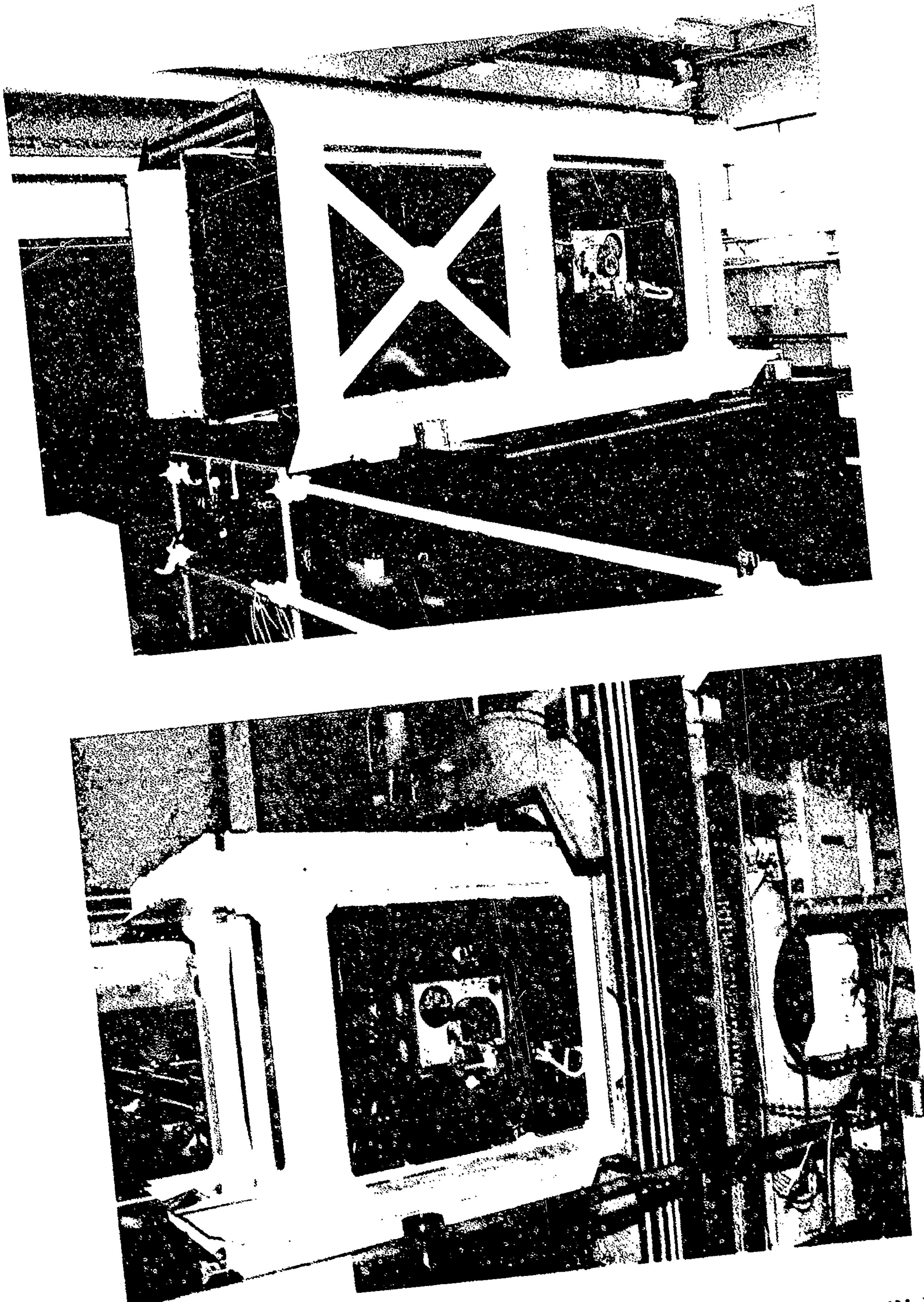


FIG. 3a: INSTALLATION OF THE INTERCHANGEABLE 2-D MODULE IN THE PLENUM CHAMBER OF THE IAR 1.5m TRISONIC BLOWDOWN WIND TUNNEL

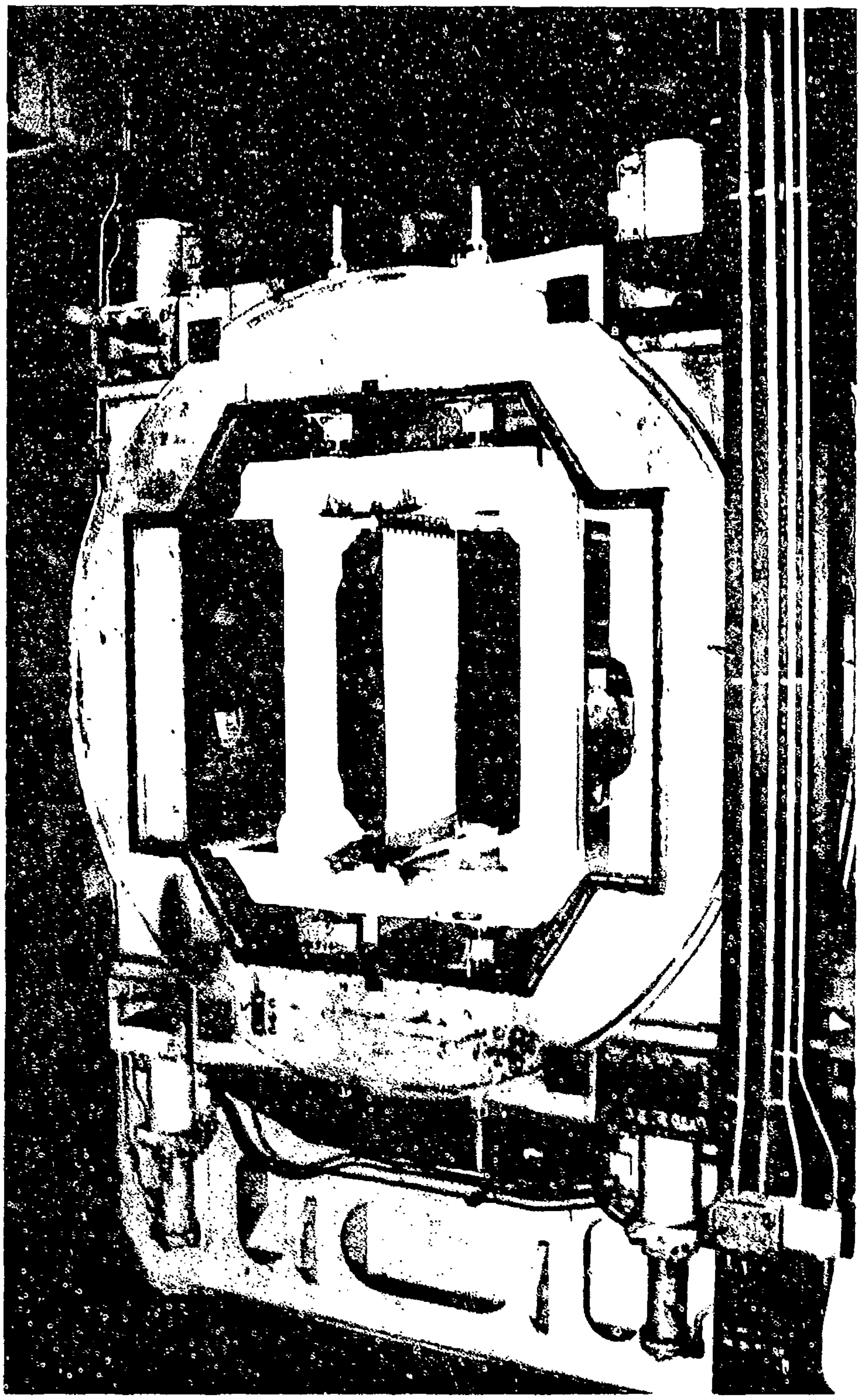


FIG. 3b: THE INTERCHANGEABLE 2-D MODULE INSTALLED IN THE PLENUM CHAMBER OF THE IAR 1.5m TRISONIC BLOWDOWN WIND TUNNEL

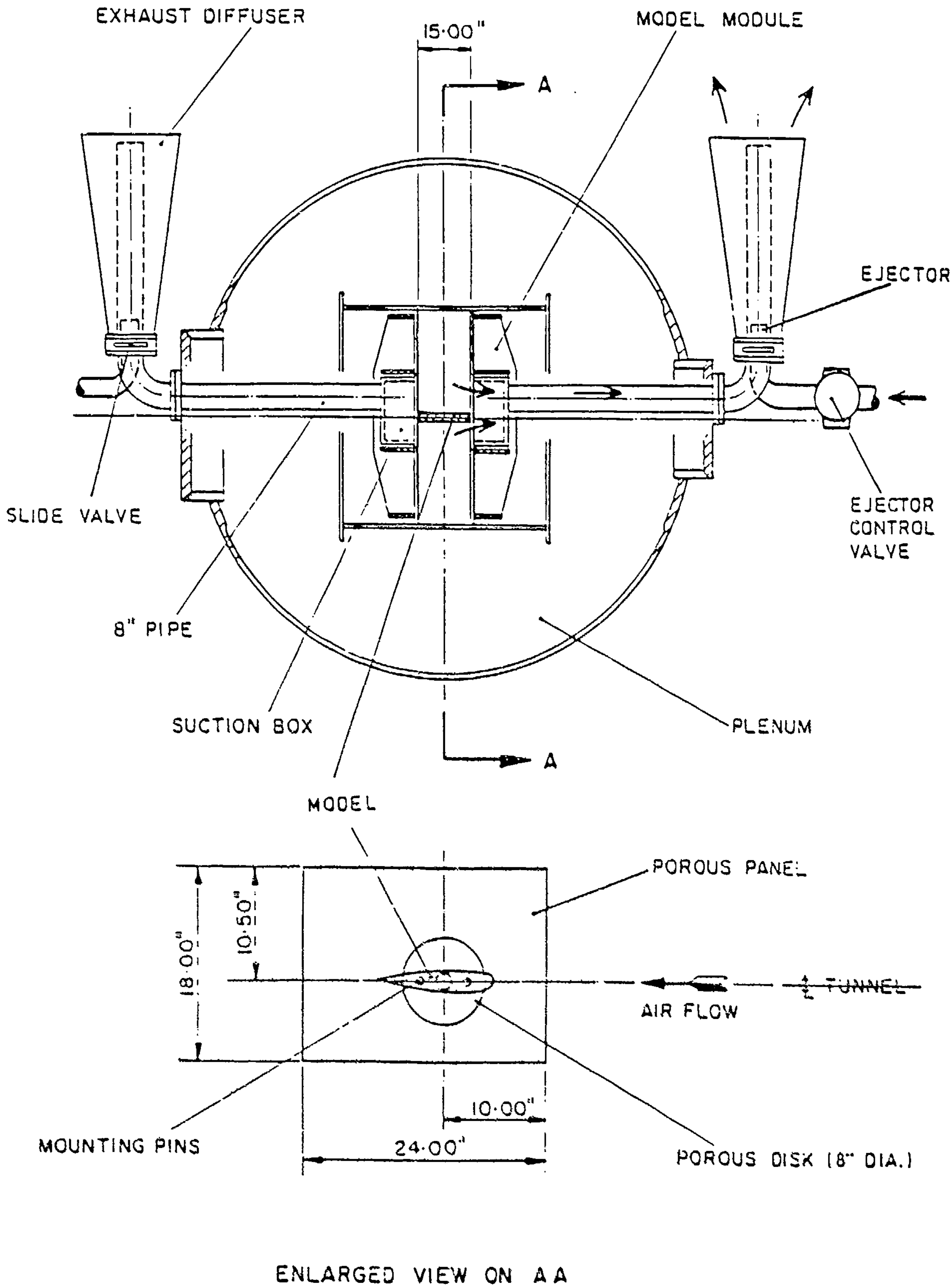


FIG. 4: THE SIDEWALL BOUNDARY LAYER CONTROL SYSTEM

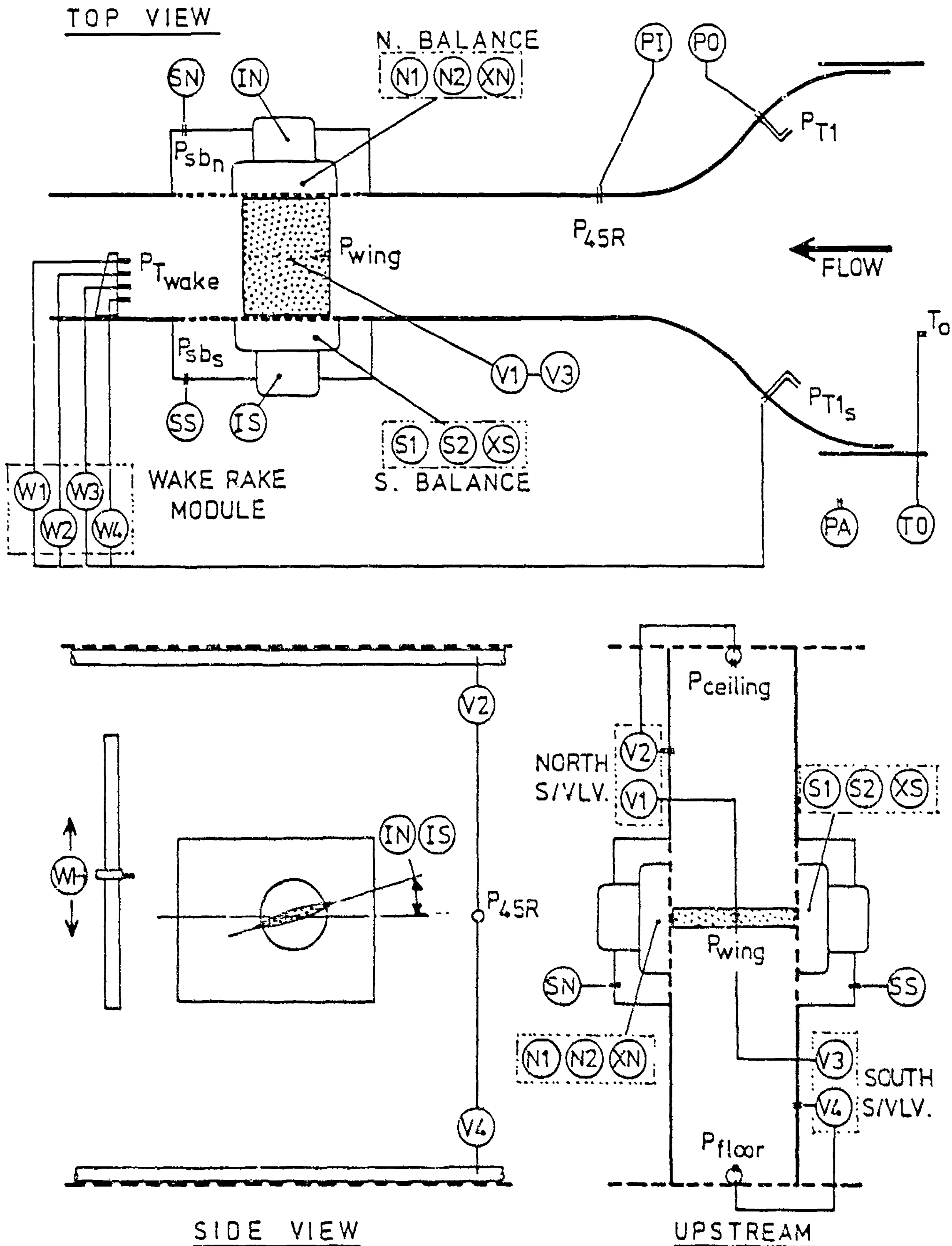
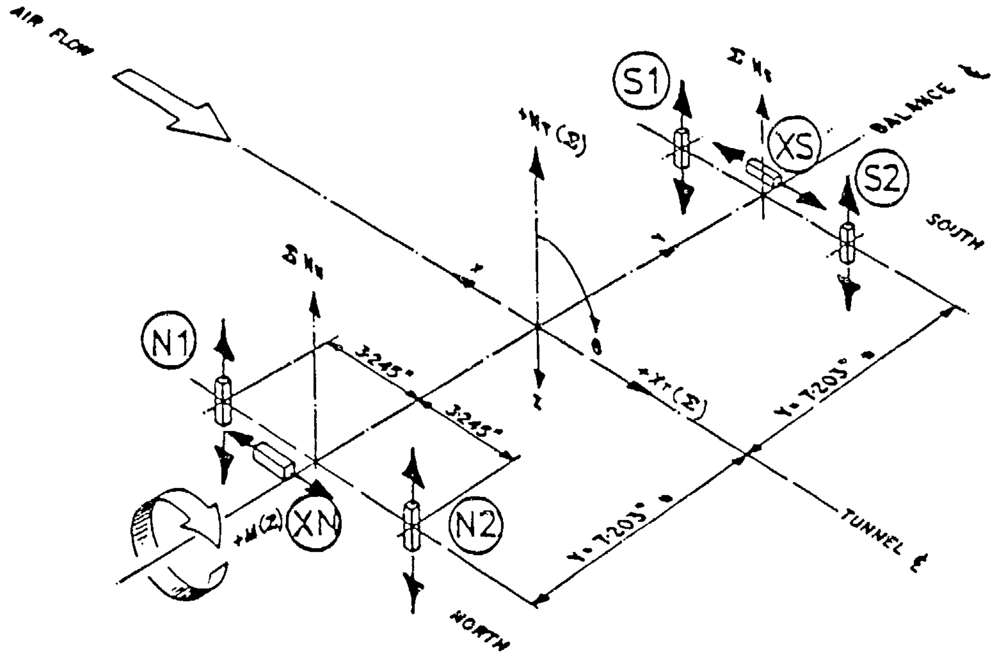


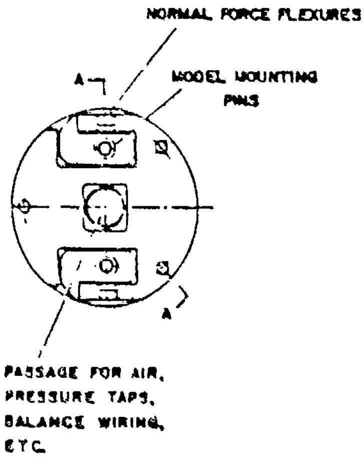
FIG. 5: SCHEMATIC OF THE PRINCIPAL TEST MEASUREMENTS

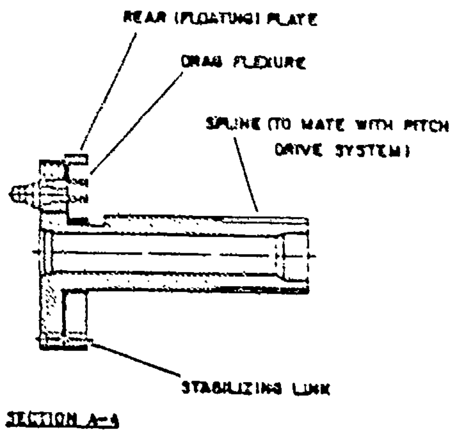


* NOTE — Y IS THE DISTANCE FROM THE TUNNEL ℄ TO 'PIN LAND' — FLEXURES ARE SHOWN SCHEMATICALLY AT THE 'PIN LAND' LOCATION

ALLOWABLE LOADING, LIMITED BY PINS		SAFETY FACTOR ON YIELD
PITCHING MOMENT:	2[4.5(5000)] = 45000 lb.in	1.5
NORMAL FORCE :	4(5000) = 20000 lbf	1.5

ALLOWABLE LOADING, LIMITED BY FLEXURES		SAFETY FACTOR ON YIELD
PITCHING MOMENT:	2[6.5(5000)] = 65000 lb.in	2.2
NORMAL FORCE :	4(5000) = 20000 lbf	2.2
AXIAL FORCE :	2(1000) = 2000 lbf	2.2





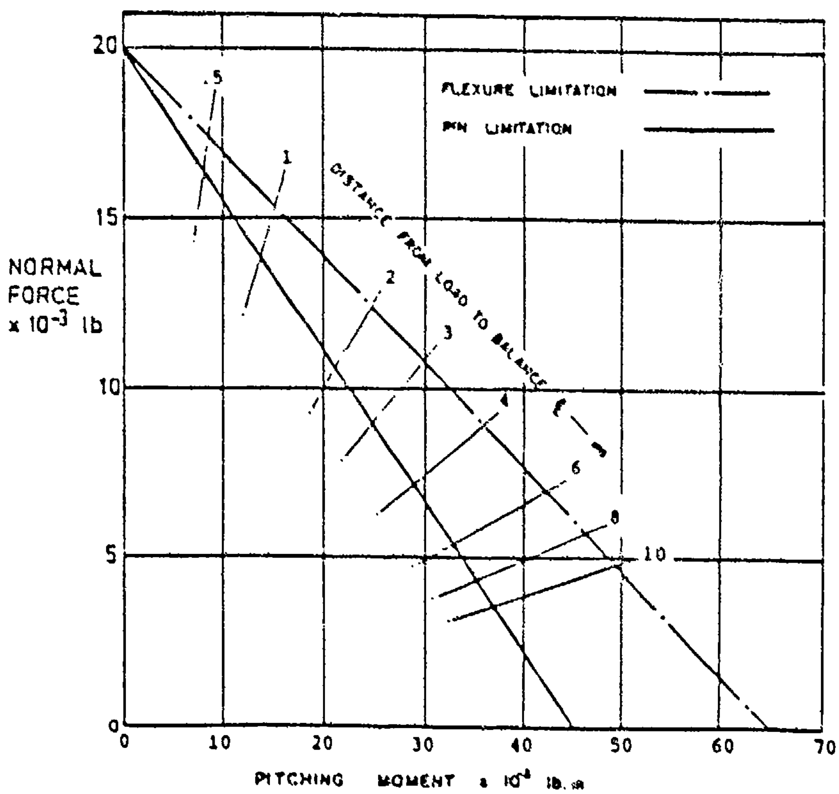
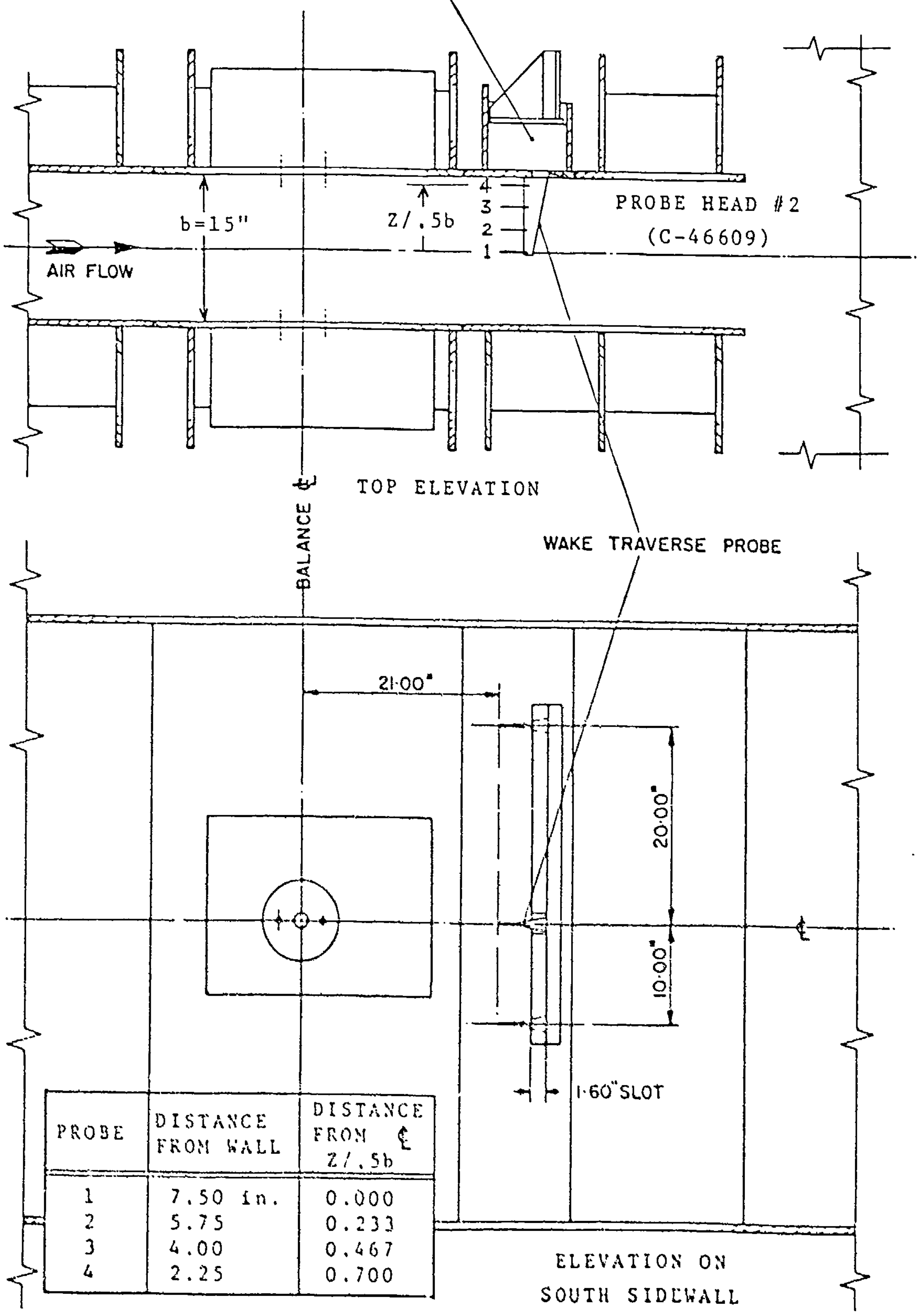


FIG. 6: THE 2-D SIDEWALL BALANCE SYSTEM



PROBE	DISTANCE FROM WALL	DISTANCE FROM ℄ Z/.5b
1	7.50 in.	0.000
2	5.75	0.233
3	4.00	0.467
4	2.25	0.700

FIG. 7: THE TRAVERSING WAKE RAKE SYSTEM

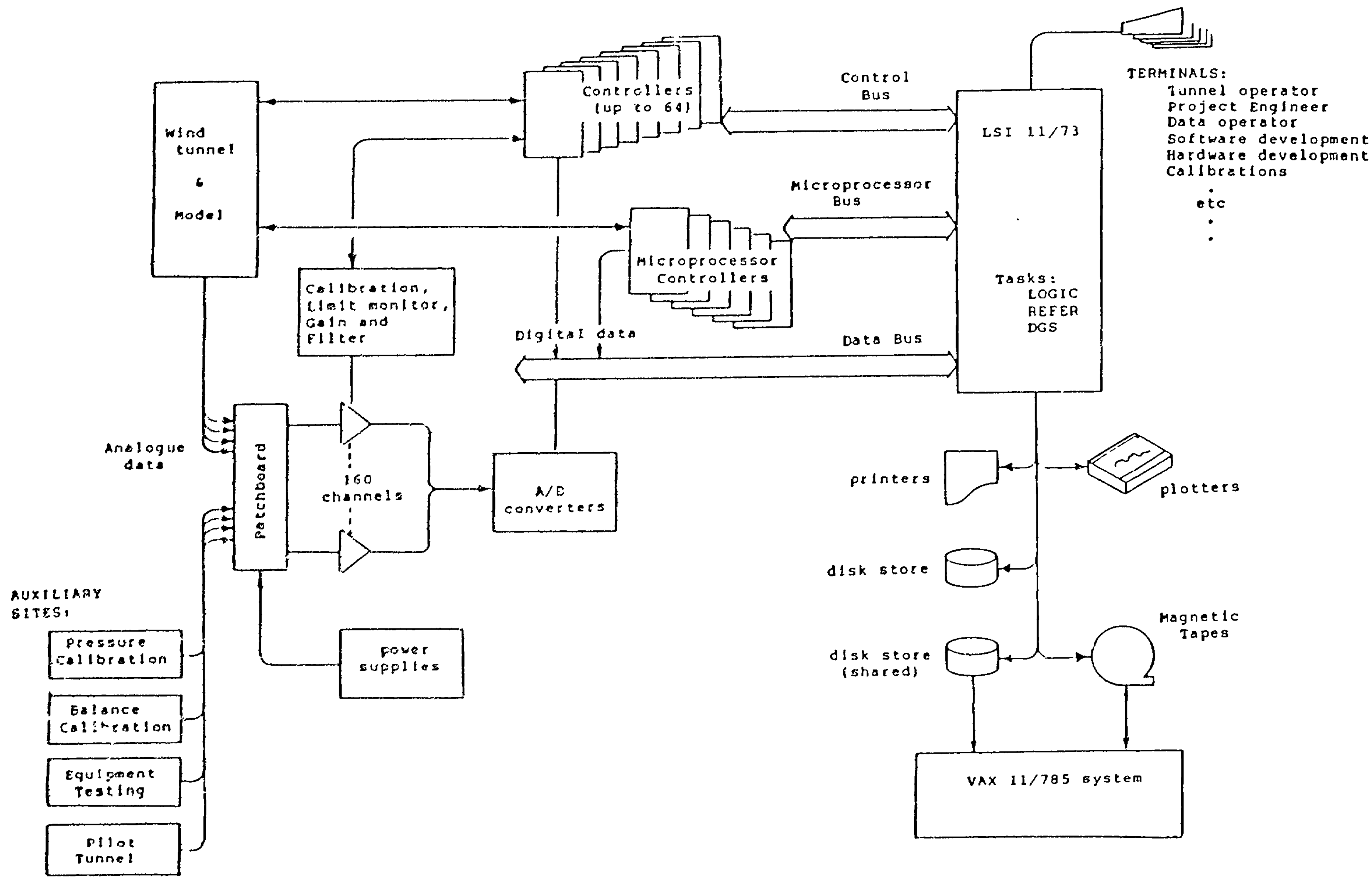


FIG. 8: THE IAR 1.5m WIND TUNNEL CONTROL AND DATA PROCESSING SYSTEM

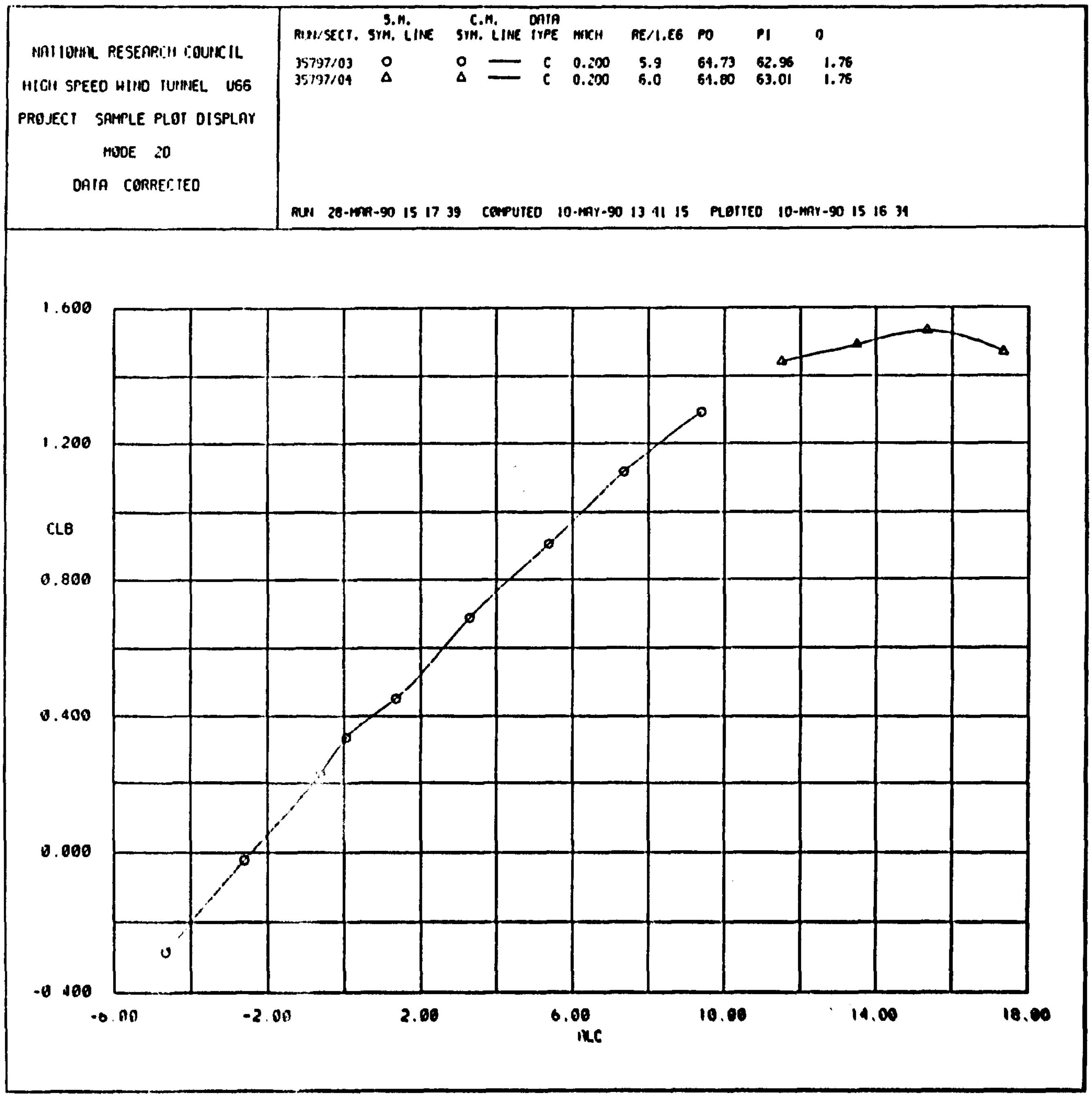


FIG. 9a: SAMPLE FORCE AND MOMENT COEFFICIENT PLOT FORMAT

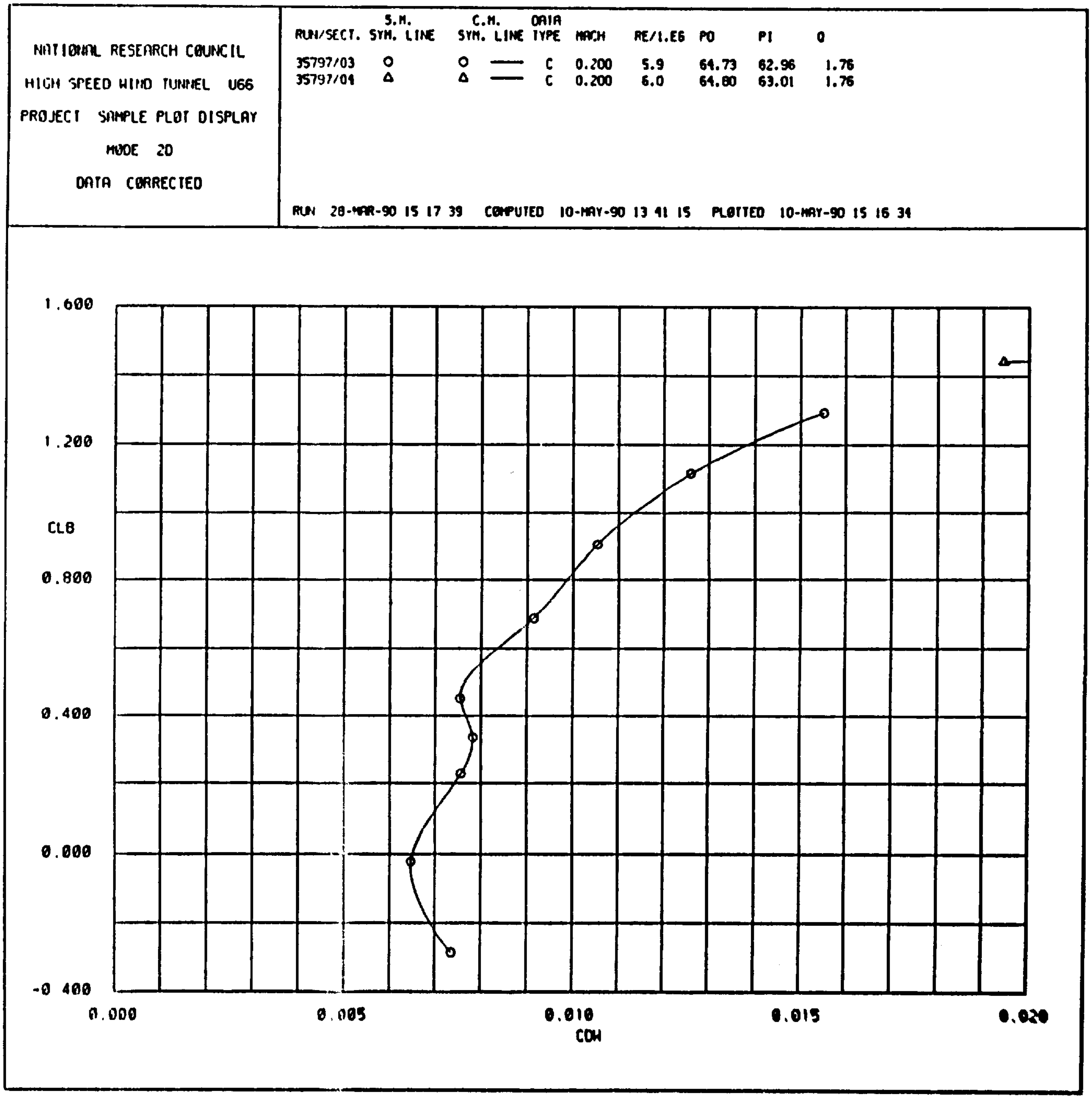


FIG. 9b: SAMPLE FORCE AND MOMENT COEFFICIENT PLOT FORMAT

NATIONAL RESEARCH COUNCIL
HIGH SPEED WIND TUNNEL U66
PROJECT SAMPLE PLOT DISPLAY
MODE 2D
DATA CORRECTED

RUN/SECT.	SCAN	SYM.	MACH	RE	CL	ALC	SET	NAME
35797/03	01	○	0.199	5.7	-0.266	-4.664	01	MAIN AIRFOIL
35797/03	02	▲	0.199	5.9	-0.018	-2.617		
35797/03	03	+	0.199	5.9	0.226	-0.619		
35797/03	04	×	0.200	6.0	0.325	0.056		
35797/03	05	◇	0.200	6.0	0.461	1.350		
35797/03	06	▼	0.199	6.0	0.682	3.303		
35797/03	07	■	0.200	6.0	0.916	5.381		
35797/03	08	*	0.200	6.0	1.126	7.371		
35797/03	09	◆	0.200	6.0	1.309	9.384		

RUN 28-MAR-90 15 17 39 COMPUTED 10-MAY-90 11 11 43 PLOTTED 10-MAY-90 12 14 41

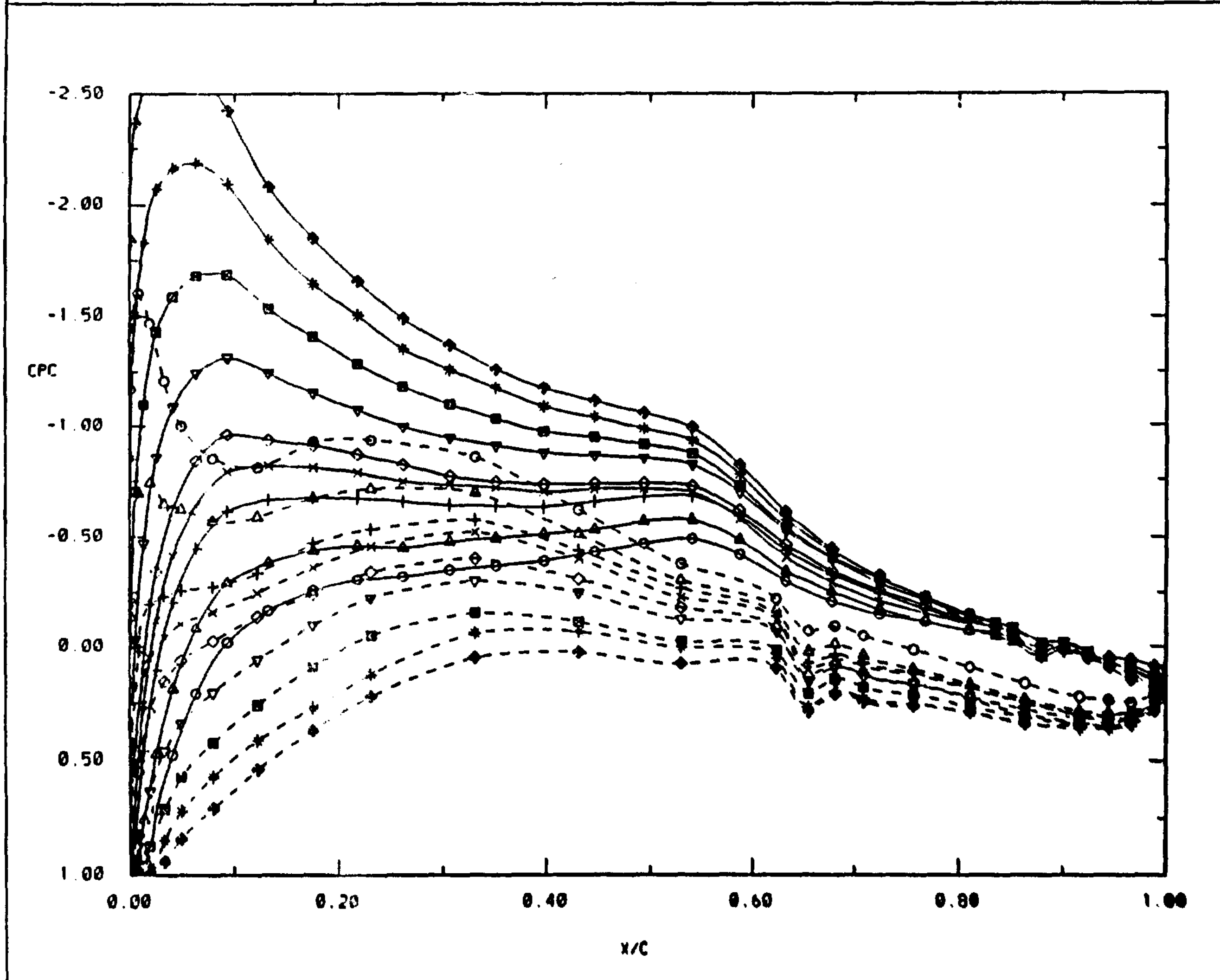


FIG. 10a: SAMPLE MODEL STATIC PRESSURE DISTRIBUTION PLOT FORMATS

MODEL STATIC PRESSURE DISTRIBUTIONS RUN 35797 - 3

PLOT WINDOW AXIS LENGTHS -- X: 3" = 0.00 to 1.00 , Cp: 2" = 1.000 to -2.500

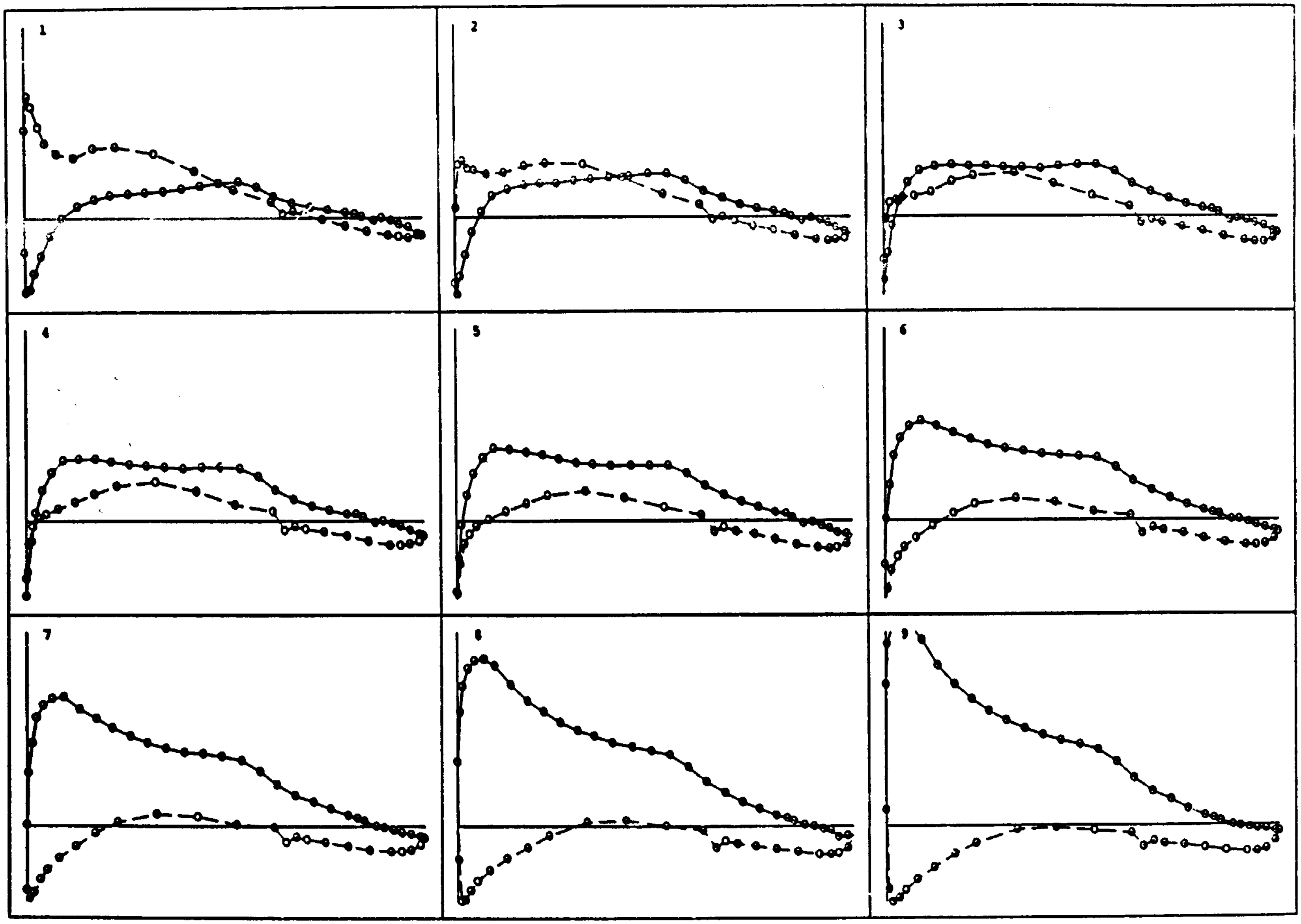


FIG. 10b: SAMPLE MODEL STATIC PRESSURE DISTRIBUTION PLOT FORMATS

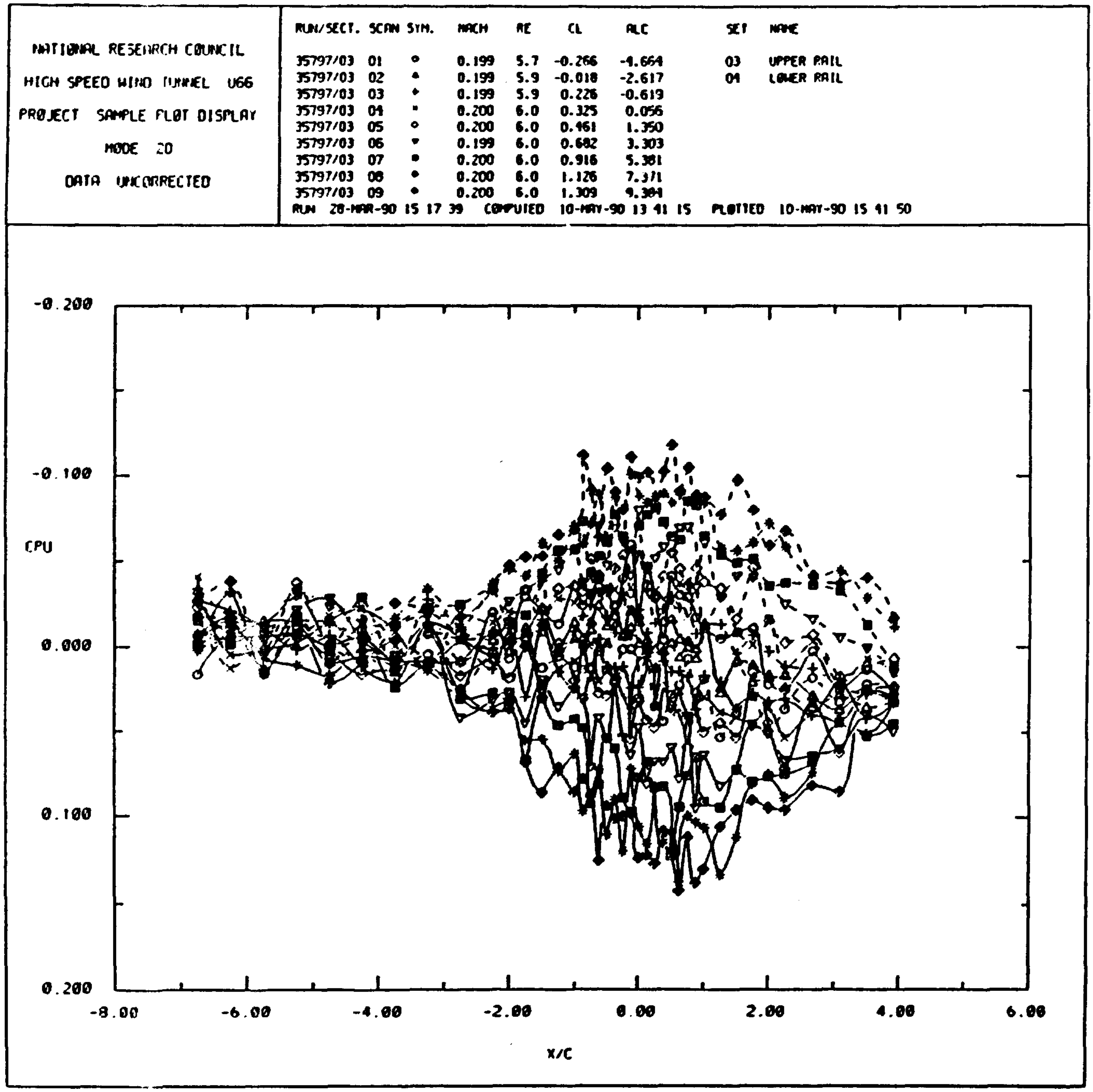


FIG. 11a: SAMPLE CEILING AND FLOOR STATIC PRESSURE DISTRIBUTION PLOT FORMATS

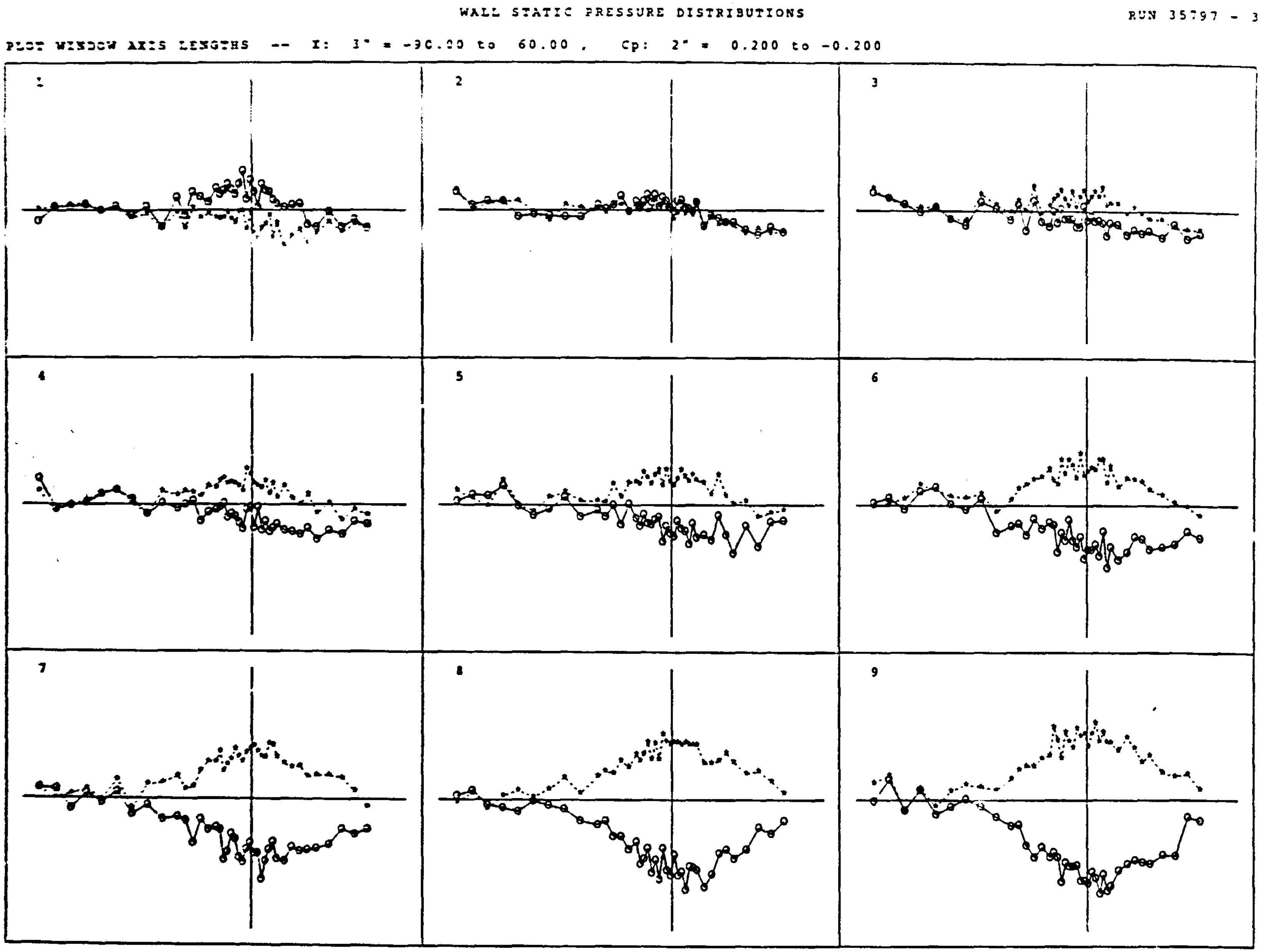


FIG. 11b: SAMPLE CEILING AND FLOOR STATIC PRESSURE DISTRIBUTION PLOT FORMATS

RUN/SECT.	SCAN	SYM.	LINE	M	RE	ALC	CLB	V/U	PO	CDW1	CDW2	CDW3	CDW4
35797/ 3	1	o	———	0.199	5.7	-4.664	-.286	0.0136	64.66	0.0078	0.0075	0.0068	0.0319
35797/ 3	2	▲	-----	0.199	5.9	-2.617	-.024	0.0134	64.68	0.0074	0.0062	0.0058	0.0334
35797/ 3	3	+	······	0.199	5.9	-0.619	0.229	0.0133	64.70	0.0080	0.0070	0.0077	0.0300
35797/ 3	4	×	· ·· ···	0.200	6.0	0.056	0.337	0.0132	64.73	0.0076	0.0074	0.0085	0.0271

RUN 28-MAR-90 15 17 39 COMPUTED 10-MAY-90 13 41 15 PLØTTED 10-MAY-90 17 13 53

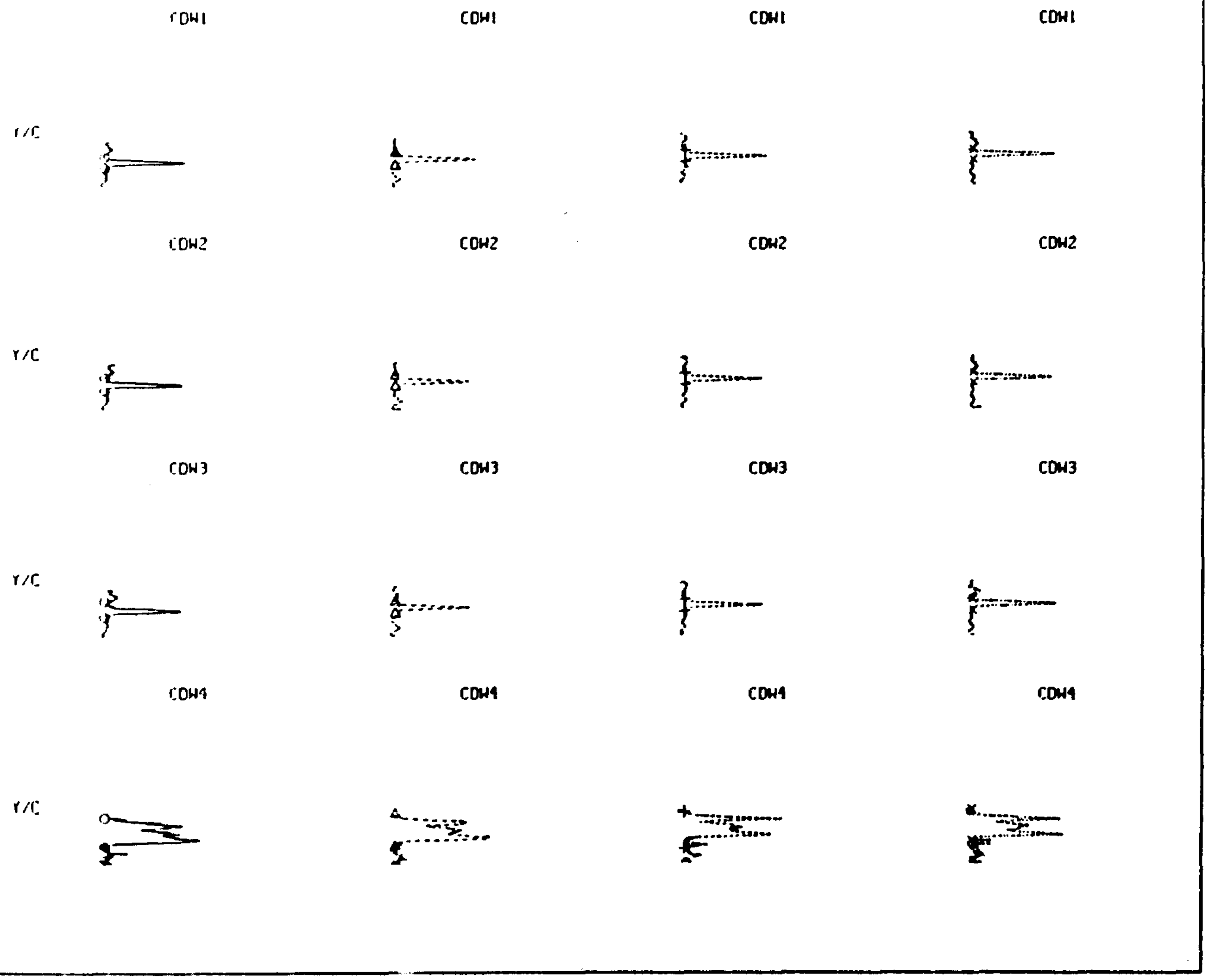


FIG. 12a: SAMPLE WAKE C_D' PROFILE PLOT FORMATS

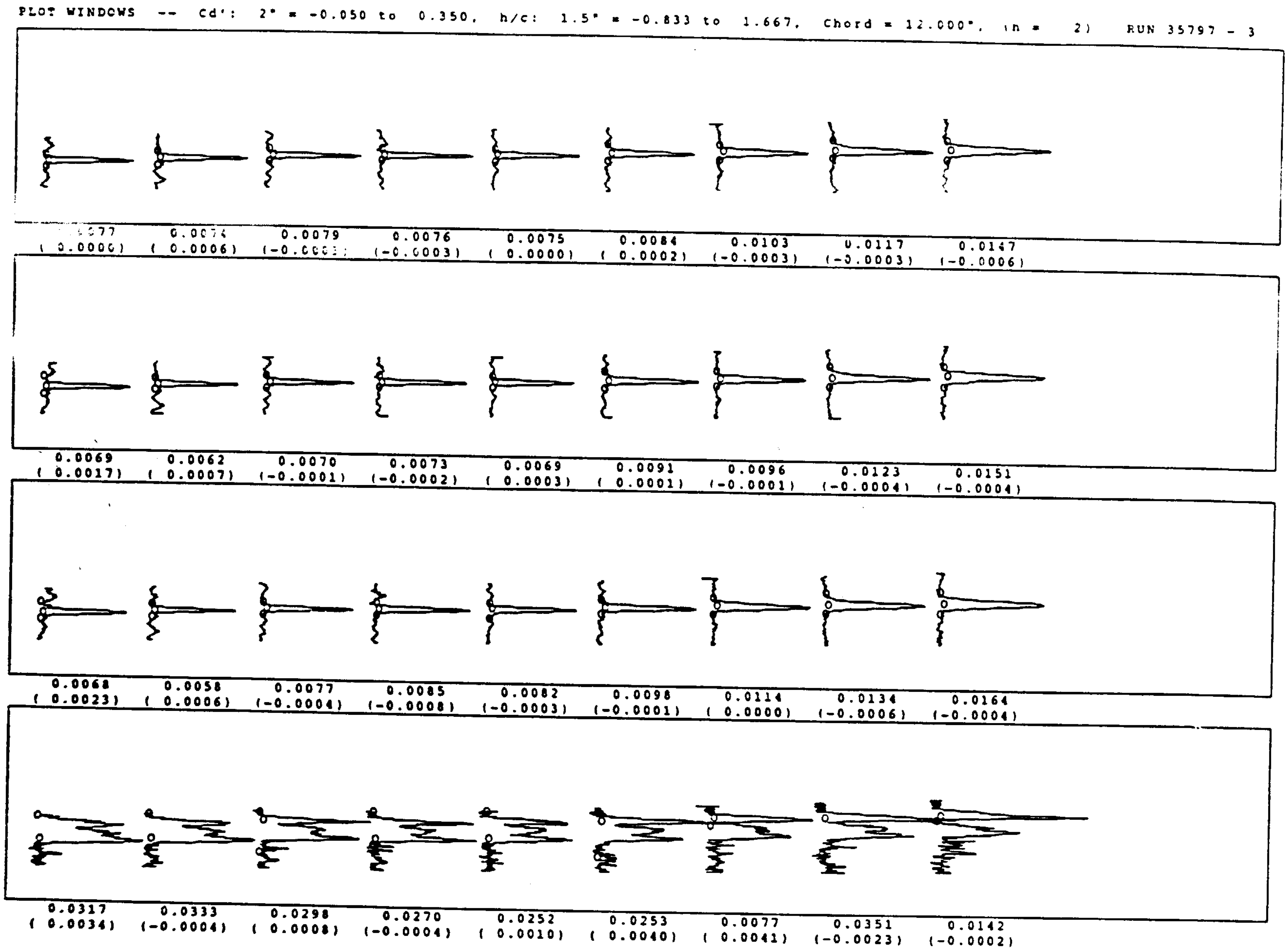


FIG. 12b: SAMPLE WAKE C_D' PROFILE PLOT FORMATS

APPENDIX A

OUTLINE OF DATA REDUCTION PROCEDURE AND EQUATIONS

The initial step in the data reduction process is to convert the raw data from data system 'counts' to engineering units using the information contained in the 'channel data' section of the master data, i.e. calibration factor, excitation voltage, amplifier gain, and zero offset. All conversions to engineering unit form, and all computations in the data reduction process, utilise the Imperial system of units, and all equations given in this appendix refer to this measurement system.

Appropriate averages of these engineering unit data are then formed based upon information contained in the appropriate 'status' channel. These averages are the 'data point' values of the quantities appropriate to a model incidence step for example, or in the case of scanned pressure measurements to a single pressure port in the Scanivalve's rotation sequence. In the case of the wake rake pressure measurements there is no averaging process, every valid data sample within the traverse, (as defined by 'status'), being converted to the C_D' form prior to integration of these values across the wake. This appendix presents the principal equations used in computing the quantities presented in the tabulated output from these engineering unit values.

(1) Free Stream Tunnel Parameters

The test section flow conditions are defined in terms of the following four measured quantities:

Stagnation pressure	- PT1, Po	(psia)
Reference static pressure	- P45R, Ps	(psia)
Stagnation temperature	- To	(deg. Rankine)
Atmospheric pressure	- Patm	(psia)

All of the pressures are measured using Digiquartz absolute transducers, with the atmospheric pressure value being recorded by all three pressure channels during the pre-run tare. The 'wind-on' stagnation and static pressures are then determined as

$$Po = (PT1)\text{wind-on} - (PT1)\text{tare} + Patm$$
$$Ps = (P45R)\text{wind-on} - (P45R)\text{tare} + Patm$$

The use of an atmospheric pressure datum, with the actual value being measured using a high-accuracy 45-psia (300 kPa) range Digiquartz transducer, minimises the effect of any long term transducer zero drifts.

A correction is normally applied to the measured reference static pressure to determine the centreline free stream value. This correction was determined from calibration of the empty test section in which a centreline pole was used to measure the static pressure, and is in the form of a pressure coefficient defining the difference between the reference (P45R) and centreline values as

$$DCP45R = (Ps - Pinf) / Qnom$$

where $$Qnom = 0.7 \, . \, Ps \, . \, Mnom^2 \quad \text{(psi)}$$

and $$Mnom = \sqrt{5 \left[(Ps/Po)^{-2/7} - 1 \right]}$$

From calibrations of the empty test section, using the 2% porosity ceiling and floor configuration determined to be optimum from preliminary results, it was concluded that the value of DCP45R was small and, because of the presence of a slight axial pressure gradient, rather difficult to define precisely. However, the wall interference correction process of Reference 6 is self-correcting in regard to small errors in the measured static pressure, and thus the computed data, when corrected for wall interference effects, will be unaffected by exactly what small value is assigned to DCP45R. This is because the correction to Mach number is derived from the ceiling and floor

pressure distributions which are themselves referenced to the measured static pressure. In these circumstances the DCP45R correction was assigned the value 'zero'. However, for generality the data reduction procedure is written to compute and apply the correction as

$$\text{Pcorr} = -\,\text{DCP45R}\,.\,\text{Qnom}$$

and

$$\text{Pinf} = \text{Ps} + \text{Pcorr}$$

even though 'Pcorr' will be zero for the current test section configuration.

The free stream flow parameters, corrected for tunnel calibration effects but not for wall interference, are computed from the isentropic relationships

$$\text{Minf} = \sqrt{5\,[\,(\text{Pinf}/\text{Po})^{-2/7} - 1\,]}$$

$$\text{Qinf} = 0.7\,.\,\text{Pinf}\,.\,\text{Minf}^2 \qquad \text{(psi)}$$

$$\text{Tinf} = \text{To}/(1 + 0.2\,.\,\text{Minf}^2) \qquad \text{(deg. Rankine)}$$

$$\text{Uinf} = 49.01428\,.\,\text{Minf}\,.\,(\text{Tinf}^{1/2}) \qquad \text{(feet/second)}$$

$$\mu = 2.27\,.\,(\text{Tinf}^{3/2})\,.\,10/(\text{Tinf} + 198.6) \qquad (\text{lb.sec/ft}^2)$$

$$\text{Re/ft} = 288\,.\,\text{Qinf}/(\text{Uinf}\,.\,\mu)$$

The values of two significant pressure coefficients are also computed. The 'critical' pressure coefficient, i.e. that for which unity Mach number is attained on the airfoil surface, is defined by

$$\text{Cpcrit} = \{[(1 + 0.2\,.\,\text{Minf}^2)/1.2]^{3.5} - 1\}/0.7\,.\,\text{Minf}^2$$

and the 'stagnation' pressure coefficient by

$$\text{Cpstag} = \{(1 + 0.2\,.\,\text{Minf}^2)^{3.5} - 1\}/0.7\,.\,\text{Minf}^2$$

(2) Model Incidence

The model incidence readings recorded at both the north (α_n) and south (α_s) sides of the dual-sided drive balance system are averaged to provide a single value of the balance X-axis inclination to the wind tunnel horizontal axis. To obtain the model incidence with respect to the tunnel flow direction, the following corrections are applied.

(1) A correction for any angle between the model chord line and the line through the centres of the mounting pin holes, (ALBAR), which is defined in line 29 of the master data 'real' constants.

(2) A correction for any flow angularity as determined from a Mach number function for the appropriate wall porosity setting. The following algorithms have been determined from calibrations of flow angularity performed at wall porosity settings of 2%, 3%, and 4%.

$$2\%:\ \Delta\alpha_{flow} = -0.053 + 0.494\,.\,M - 0.316\,.\,M^2$$

$$3\%:\ \Delta\alpha_{flow} = -0.0053 + 0.1933\,.\,M$$

$$4\%:\ \Delta\alpha_{flow} = -0.202 + 0.55\,.\,M$$

The model angle of attack, before correction for wall interference, is thus

$$\alpha_c = (\alpha_n + \alpha_s)/2 + \text{ALBAR} + \Delta\alpha_{flow}$$

(3) Finally, a correction to account for wind tunnel wall constraint effects, (as determined by the method of Reference 6), is added to the above value.

(3) Balance Forces and Moments

Pre-run balance tare data acquired at three different model attitudes are processed by the method described in Reference 7 to yield the coefficients in a set of equations which relate the model weight and centre of gravity location with the balance component loads. These equations are functions of the model attitude and are used to compute the tare weight effects on each balance component at the required attitude.

The 3-component load vector { NF, NA, XT } is formed from the measured load vector {N1, N2, XN, S1, S2, XS } as

$$NF = (N1 + S1), \quad NA = (N2 + S2), \text{ and } XT = (XN + XS)$$

and corrected for balance interactions. Subtraction of the tare weight effects appropriate to the given attitude then yields the model aerodynamic loads. From this 3-component form the total forces and moments, { NT, mT, XT } are computed as

$$NT = \{ (N1 + S1) + (N2 + S2) \} = NF + NA$$

$$mT = 3.245 \, (NF - NA) \quad \text{(component spacing = 6.49")}$$

and

$$XT = XN + XS$$

This vector, still in a balance axis system, is transformed to a model axis system with pitching moment transferred to the required reference point, and converted to coefficient form thus:

$$\begin{aligned} CNB &= (NT \,.\, \cos \bar{\alpha} + XT \,.\, \sin \bar{\alpha}) / Q.S \\ CXB &= (-NT \,.\, \sin \bar{\alpha} + XT \,.\, \cos \bar{\alpha}) / Q.S \\ CmB &= (mT - NT \,.\, Xref + XT \,.\, Zref) / Q.S.c \end{aligned}$$

where

$\bar{\alpha}$ = ALBAR = angle between model chord and balance X-axis,
c = model chord,
S = model reference area (= 16 x chord in inches),
Xref = axial distance from balance centre to model moment reference point, (+ve upstream)
Zref = vertical distance from balance centre to model moment reference point, (+ve down).

The constants noted are all contained in the 'real' constants section of master data; Xref and Zref are measured in a balance axis system.

Finally the above model-axis coefficients are resolved to lift, drag, and pitching moment in wind axes as

$$CLB = CNB \,.\, \cos \alpha_c - CXB \,.\, \sin \alpha_c$$

and

$$CDB = CNB \,.\, \sin \alpha_c + CXB \,.\, \cos \alpha_c$$

where α_c has been defined under (2) above.

(4) Airfoil Surface Pressures

The airfoil surface pressure distributions are expressed in standard pressure coefficient form as

$$\text{Cpwing} = (\text{Pwing} - \text{Pinf}) / \text{Qinf}$$

and as the pressure ratio

$$\text{Pratio} = \text{Pwing} / \text{Po}$$

from which the local Mach number is also computed as

$$\text{Mwing} = \sqrt{5\,[\,(\text{Pratio})^{-2/7} - 1\,]}$$

The normal and axial force, and pitching moment, coefficients are determined from the surface pressure coefficients according to the following contour integrals, which are evaluated using a modification of Simpson's Rule to account for unequal ordinate spacing. This algorithm is attributable to Brun and has been described by Nonweiler in Reference 9.

$$\text{CNP} = \oint \text{Cpwing} \,.\, d(x/c)$$

$$\text{CXP} = - \oint \text{Cpwing} \,.\, d(z/c)$$

$$\text{CmLE} = -\{ \oint \text{Cpwing} \,.\, (x/c) \,.\, d(x/c) + \oint \text{Cpwing} \,.\, (z/c) \,.\, d(z/c) \}$$

The pitching moment coefficient about the reference point is then

$$\text{CmRP} = \text{CmLE} + 0.25 \,.\, \text{CNP} + (\text{Zp-ref}/c) \,.\, \text{CXP}$$

where Zp-ref is the distance of the moment reference point from the airfoil chord line, (along a normal to the chord and positive in the downward direction). Note that 'Zp-ref' should not be confused with 'Zref', noted under (3) above, which defines the distance of the moment reference point from the balance centre, measured normal to the balance X-axis; 'Zp-ref' is defined in line 8 of the 'real' constants in master data.

These force and moment coefficients are also expressed in a wind-axis system defined by equations similar to those presented for the balance coefficients in (3) above.

(5) Wake Traverse Drag Data

Total pressure profiles are measured, at four spanwise stations in the airfoil wake, differentially with respect to the free stream stagnation pressure. These measurements are first converted to absolute pressures defining the total pressure deficit in the wake, and then to coefficient form using the equation for C_D' which is given below. The section drag coefficient C_{Dwi}'' then is obtained by integration of C_D' across the extent of the wake. The 'wi' refers to the probe in use, (W1 ... W4), and in general

$$C_{Dwi}'' = \int C_{Dwi}' \,.\, d(h/c)$$

The full expression for the coefficient C_D' can be found in Reference 10. If it is assumed that the static pressures both inside and outside the wake are equal to the free stream static pressure, (and this assumption is quite commonly accepted and is used at HSAL), the following simplified expression is obtained.

where

$$C_{Dwi}' = 2 \,.\, A \,.\, C \,.\, (1 - C)$$

$$A = (Powi\ /\ Po)^{2/7}$$

$$B = (Pinf\ /\ Powi)^{2/7}$$

and

$$C = \sqrt{\{(1 - B)\ /\ (1 - A\,.\,B)\}}$$

Here 'Po' and 'Powi' are the total pressures in the freestream and the wake respectively, and 'Pinf' is the static pressure.

The integration noted is performed using the trapezoidal rule between limits determined from an algorithm. These limits are designed to eliminate from the integration, data from outside the edges of the wake as the inclusion of noise, (with a mean value of zero in the pressure domain), will result in some small negative contribution to the integrated drag value. The basis of the algorithm is first to detect the positions in the wake at which the C_D' value falls below a test cut-off level, (CDCUT), the search for these positions being made in an outward direction from the peak pressure deficit location. The second stage of the limit definition is the extension of these two 'peak to cut-off' distances by a specified percentage, (IPCNT); this is to make allowance for the fact that the cut-off level cannot be set too close to a zero value of C_D' because of experimental considerations. This simple algorithm has been found to define satisfactory integration limits for a wide variety of pressure profiles in both sub-critical and super-critical flows. It is normal practice to provide 'quick-look' plots of the C_D' profiles following each run, and to show the calculated integration limits on the plots. The values of CDCUT and IPCNT are constants in master data and can be varied to adjust the placement of the limits; typical values are indicated by the following ranges:-

CDCUT = 0.001 to 0.005, IPCNT = 50 to 75%

While the C_D' profile should theoretically approach a zero value at the edges of the wake, it is possible that the experimental data may in fact show some small finite values at the defined integration limits. To obtain a correct determination of the area under the curve, the 'baseline' should really be taken as the line joining the average values of C_D' at the edges of the wake. This objective is accomplished by first integrating with respect to the "$C_D' = 0$" baseline, and then correcting the area thus determined by subtracting a trapezoidal area determined from the distance between the wake edges and the values of C_D' at each edge.

Thus

$$\Delta i = 0.5\,[\,C_{Du}' + C_{Dl}'\,]\,.\,[\,(h/c)u - (h/c)l\,]$$

where

C_{Du}', C_{Dl}' = upper and lower wake limit values of C_D',
$(h/c)u, (h/c)l$ = upper and lower integration limits, and

$$C_{Dwi} = C_{Dwi}'' - \Delta i \quad \text{for } i = 1 \text{ to } 4$$

(6) Sidewall Boundary Layer Suction

The level of boundary layer flow removal through the porous (Rigimesh) panels is expressed as the ratio of the velocity normal to the wall relative to that in the stream direction, i.e. (Vn / Vinf). This quantity is determined from measurements of the suction box pressures on each side of the test section, knowing the pressure loss constants of the porous panels.

The expression for (Vn / Vinf) is

$$(Vn/Vinf) = \{1/(K.M)\}. \sqrt{[(Pinf\text{-}Psb)/Po].[1+0.2M^2]^{3.5}}$$

in which 'K' is the Rigimesh loss coefficient, and the ratio is evaluated independently for the north and south sides using the appropriate suction box pressure measurement and loss coefficient. The porosity values of the two Rigimesh panels are not the same with the north panel being more resistive to flow; from calibration the north and south 'K' values were found to be in the ratio '82:71'. In addition to the individual north and south side values, an average value is given in the tabulations; typically deviations between the individual and average values are less than approximately 0.0003 at the nominal setting of 0.0083 which is considerred optimum for most tests involving single element airfoil models.

(7) Tunnel Wall Interference Corrections

Measurements of the static pressure distributions on the top and bottom walls of the test section are used to determine the corrections to Mach number (ΔM) and model angle of attack ($\Delta\alpha$) necessitated by the flow constraints imposed by the wind tunnel walls. These corrections are determined by the Fast Fourier Transform method described in Reference 6, which provides quantitative values of the two correction quantities as functions of the axial location in the test section. For application of the corrections to the measured data values, the Mach number and incidence corrections determined at the location of the model quarter chord are used.

The Mach number is corrected as follows

$$Minf = Minf' + \Delta M$$

where "Minf'" is the Mach number corrected only for tunnel calibration effects. A corrected static pressure is then determined from the isentropic relation

$$Pinf = Po / (1 + 0.2 . Minf^2)$$

Values of all other quantities noted in the preceeding sections are then finally corrected for these wall interference effects as manifested by changes in the stream Mach number and model angle of attack. In correcting pressure coefficients the changes in both static pressure and dynamic pressure, (resulting from the change in Mach number), are considered, while for the force and moment coefficients corrected values are obtained simply by multiplication of the uncorrected values by the ratio of the uncorrected to corrected dynamic pressure. After correction of the model angle of attack the model-axis coefficients are transformed to wind axes as indicated in (3) above.

(8) Real Time Mach Number Control Constant

The wall interference correction to Mach number has been found to be an almost linear function of the lift coefficient, and this fact is used to provide real time control of the 'corrected' Mach number. In the control microprocessor the lift is represented by measurement of the difference between the ceiling and floor static pressures sensed at approximately the model quarter chord location, and the approximate correction to Mach number is defined in terms of the absolute value of this pressure coefficient as

$$M = K . [M (1 + 0.2M^2) / (1 - M^2)] . | Cp |$$

where 'K' is a constant in the range 0.025 to 0.03 for most models tested in the interchangeable 2-D test section module when using 2% ceiling and floor porosity.

As a continuing check on the suitability of the chosen constant value, the data reduction process includes a linear curve fit of the actual Mach number corrections, (determined from the ceiling and floor pressure distributions), against the absolute value of the 'Ceiling - Floor' pressure coefficient. The curve fit is made with a free intercept value, (which is ignored), the slope being noted in the output tabulations for monitoring purposes only.

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4 The IAR High Reynolds Number Two-Dimensional Test Facility – A Description of Equipment and Procedures Common to Most 2-D Airfoil Tests

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DESCRIPTORS (KEY WORDS)/MOTS-CLÉS

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1. Wind tunnel tests
2. Trisonic wind tunnels
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SUMMARY/SOMMAIRE

This report describes features and operational procedures which are common to the great majority of wind tunnel test projects conducted in the Two-Dimensional (2-D) Test Facility of the Institute of Aerospace Research 1.5m Trisonic Blowdown Wind Tunnel in Ottawa, Canada. It is intended to be used as a reference document describing the 'facility specific' aspects of tests performed in the above facility, to be referred to by test reports for individual projects, so allowing those reports to concentrate on aspects which are specific to the particular model and test. The report describes the 2-D test facility as modernized by the commissioning of a new interchangeable 2-D test section module in early 1989. The document will be updated periodically to ensure that it correctly reflects current capability and practice.

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